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DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 62

MODERN PRACTICE IN THE CONSTRUCTION AND MAINTENANCE OF RAIL JOINTS AND BONDS IN ELECTRIC RAILWAYS

BY

E. R. SHEPARD, Associate Electrical Engineer

Bureau of Standards

ISSUED MARCH 10, 1916

WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

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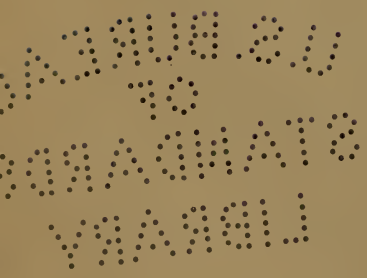

MODERN PRACTICE IN THE CONSTRUCTION AND MAINTENANCE OF RAIL JOINTS AND BONDS IN ELECTRIC RAILWAYS

By E. R. Shepard

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I. INTRODUCTION

While studying electrolysis and electrolysis mitigation during the past five years the subject of rail bonding and track conductivity has been brought forcibly to our attention by observations on railways where electrolysis surveys have been made, by a vast amount of discussion of the subject in the technical press, and by conversation and correspondence with railway engineers. This keen interest in track bonding originated largely through the necessity of mitigating electrolysis, and while electrolysis continues to be the greatest stimulus for bond maintenance, it is as a rule justifiable solely from the standpoint of good operation, and is an absolute necessity for the successful operation of block signals.

In view of the great variety of bonds and bonding practices in use at the present time, and the large percentage of failures after 25 years of experimentation on the part of the operating and manufacturing companies, and after repeated calls for information and advice on the subject from railway engineers, the Bureau of Standards deemed it advisable to institute a thorough investigation regarding the present status of bonding and joint maintenance with the idea of disseminating information that will aid the companies in selecting bonds and joints, and in methods of applying and installing them, as well as of calling attention to the importance of good track conductivity and its true relation to electrolysis and its effect upon electric railway operation.

Owing to the peculiar nature of the services that rail bonds and joints are called upon to perform and the great variety of conditions under which they operate, it was recognized that information obtained under service conditions over a period of years would be far more reliable and satisfactory than any laboratory or short-time tests that could be conducted. Many laboratory tests have been made by the manufacturers on the durability and resistance of different types of bonds and joints, and while such tests are valuable in determining the characteristics of a bond, they can not be taken as a criterion for the performance of the average bond under service conditions.

The personal element which enters so largely into the installation of bonds, and the variety of conditions under which they operate made it necessary to obtain information from a large number of sources and to base conclusions only on testimony submitted by a great many witnesses. Accordingly, data were collected through a large number of circular letters and other correspondence, by personal visits to some 50 operating companies, as well as to practically all of the manufacturers of bonds and rail joints.

Owing to the rapid growth of the electric railways, the numerous changes in the standards of construction, the improvements in materials and methods, the franchise and street-paving requirements, the changes in organization and administration, and the transient nature of the engineering staffs, it was found difficult to get definite and consistent information regarding the operation of any type of bond or joint over a period of years. Many of the companies consulted had kept only meager, if any, records of their bonding, and their replies, of necessity, were based largely on opinions. Few engineers were able to give with any degree of certainty the average life of a given type of bond. Either the bond had not been in service long enough to warrant a statement or else no definite records were available.

New inventions and recent improvements in the manufacture and installation of bonds and joints, as well as changes in the types and composition of rails, all contribute to an unsettled condition at the present time, which means that a great number of bonds and joints now in service are in the experimental stage.

While the larger operating companies have the engineers and resources with which to meet the bonding problem with more or less success, the smaller companies must depend in a large measure upon these and other external sources for their standards. This has not always been to their advantage, as many practices employed by the larger companies are not applicable to the smaller systems. Local conditions or city restrictions frequently limit the types of bonds that might be employed. The result is that many companies have been confused by the apparent inconsistencies in adopted standards, not realizing that each has been worked out to meet peculiar conditions.

A great many railways have settled on certain bonding standards and are apparently satisfied with the results they are obtaining, not that they believe they have the one and only best standard, but they are tired of experimenting and are willing to let well enough alone. Others, and perhaps the majority of the companies, are not satisfied with their present practices, and are looking for something better suited to their requirements.

In view of the conditions described above it can not be expected that this investigation will clear up a most vexatious question, nor in any way purport to be the last word on the subject. The Bureau of Standards hopes, however, in tabulating and analyzing the data which have been collected, to discern and interpret the present tendencies and to reconcile some apparent inconsistencies and differences of opinion. Its aim will have been fulfilled if it succeeds in laying before the electric railway companies, and particularly the smaller companies with limited resources, information which will be a guide to the selection of bonds and joints; and, what is of still more importance, in pointing out the best methods of application and maintenance and in emphasizing the necessity of adhering to them.

II. HISTORICAL AND GENERAL DISCUSSION OF BONDS AND JOINTS

Although early attempts were made to operate cars on unbonded tracks, relying upon the joint plates and the earth for conductance, it soon became evident that a metallic bond was necessary both from the standpoint of good operation and for the prevention of

stray currents, which were early found to have a corrosive action on underground structures.

Numerous types of iron and copper bonds came into use, many of which are now obsolete, and a description of which would be of no particular value to this paper. Those types which have found general use will be discussed with reference to their features of installation and the conditions under which they operate. No academic classification of bonds will be attempted.

The great number of different types of bonds which have appeared in the past years is largely the result of attempts to better meet the exacting requirements which this piece of apparatus is called upon to fulfill.

While these requirements and the different types of bonds which they have called forth are familiar to the majority of railway engineers, the most important of them are here briefly described by way of introduction to a later part of the paper, where, in connection with testimony submitted by the operating and maufacturing companies, a more detailed account of the manner in which the various types of bonds are meeting the requirements of service will be discussed.

1. BOND REQUIREMENTS

(*a*) INTIMATE AND PERMANENT CONTACT WITH RAIL UNDER SERVICE CONDITIONS.—Perhaps the first and most important requirement of a rail bond is that it make good electrical contact with the rail and that this contact remain good over a period of years while subjected to the mechanical vibrations of traffic, changes of temperature, the action of soil and moisture, and to the mechanical injuries from workmen and vehicles. In general, three methods of making contact with the rail have been employed, viz, soldering, mechanical, and brazing or welding. Combinations of these have also been used. Each method will be treated under the types of bonds employing it.

(*b*) DURABILITY.—The durability of the bond itself depends, first, upon its ability to withstand the bending and vibration incident to expansion and contraction of rails and the deflection of the rail joint under traffic, and, second, upon its ability to withstand electrolytic and soil corrosion.

The first action is by far the more severe and has resulted in the failure of more bonds than has any other one cause. Loose rail joints are the chief cause of such failures, and the problem of bonding is therefore intimately related to the problem of joint maintenance.

The second cause of deterioration, that of corrosion, is rarely important, although in extreme cases it may be serious. Iron bonds buried in the earth and copper bonds in soils of certain character, or on tracks from which large leakage currents are escaping, have been known to corrode at a very rapid rate.

(*c*) Ease of Installation Under Service Conditions.—For the greatest practical value a bond should be of such a nature that it can be safely and quickly installed under service conditions; that is, while traffic is being maintained over the tracks. For new work this may not be required, but for repair and replacement work its importance is obvious. While bonds are frequently installed at night and traffic is sometimes diverted for the purpose of installing bonds, such practices are decidedly objectionable. Moreover, it is possible for bonding apparatus to offer a hazard to the safe operation of cars. Though not of prime importance, these features can not be neglected in the selection of a bond.

(*d*) Low Resistance.—Under ordinary conditions the resistance of a bond within moderate limits is subordinate to its other qualities. Obviously, it must have a cross section sufficiently large to carry the track current without undue heating, but as a rule its length will be determined by other considerations. Where the resistance of bonded joints is limited by ordinance, or where for special reasons a high conductance is required, this feature may be a determining factor in the selection of a bond.

(*e*) Proof Against Theft.—In many localities the theft of rail bonds has become so prevalent and the losses from this source so heavy that the resources of the railways have been seriously taxed to cope with the problem. To-day no bonding of suburban track can be undertaken without due consideration of this feature, and either bonds designed to overcome this trouble must be selected or some other preventive means employed.

(*f*) Reasonable Cost.—While the consideration of cost can not be neglected in the selection of apparatus and material, its promi-

nence may in some instances be entirely overestimated. It is not always apparent that ultimate economy may result from a high first cost, and with the difficulty in securing approval of estimates for bonding from those who do not always appreciate the importance and necessity of this work the more expensive bond is likely to be seriously handicapped in its bid for consideration. Although the general manager who wants to know why bonding is necessary when the cars are operating under existing conditions is rather the exception, there are many who place bonding at the end of the budget, so that the engineer is sometimes forced to employ material and methods for the sake of economy which are against his better judgment. It is quite evident, therefore, that the first cost of a bond, which of course includes the cost of installation, although having little relation to its ultimate economy, in many cases might be the determining feature in its selection.

2. TYPES OF BONDS

(*a*) OLD TYPES.—Early bonding was accomplished by riveting or bolting solid iron or copper wires to the web or base of the rails. This general practice was not long employed, as it was soon found that such contacts rapidly deteriorated from corrosion. Practically none of these bonds are in use at the present time and the types can be considered as obsolete.

Channel-pin bonding, as shown in Fig. 1, consists in driving a grooved plug into a hole in the rail with a round wire fitted into the groove in the plug, found early favor with the railway companies owing to its low cost and ease of installation. It is still to be found in service on old tracks and has a very limited sale at the present time for temporary use in mines and for other special purposes. These special conditions, however, are being met by modern and more satisfactory types, thus leaving this bond with a very limited field.

Originally steel plugs and solid copper wires were used, but the practice has been varied by the use of copper instead of steel plugs and in other cases by copper-plated or tinned plugs. Sometimes the plug entirely encircles the wire in the form of a sleeve.

Although there are cases on record where this type of bond maintained good electrical contact with the rail for many years

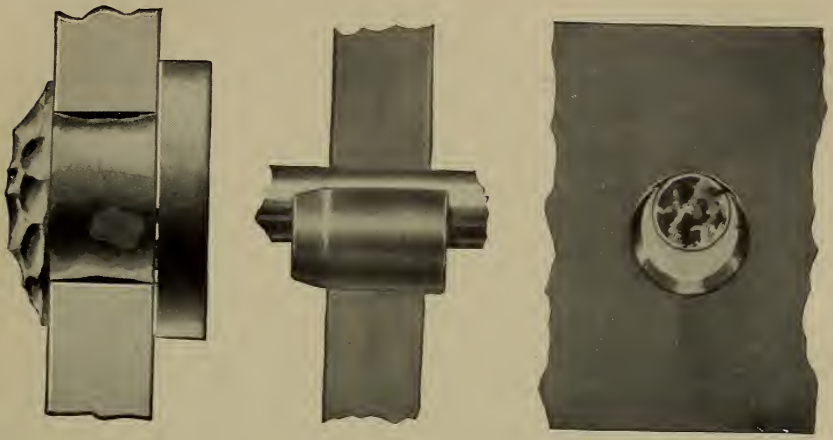

FIG. 1.—*Riveted and channel pin bonds*

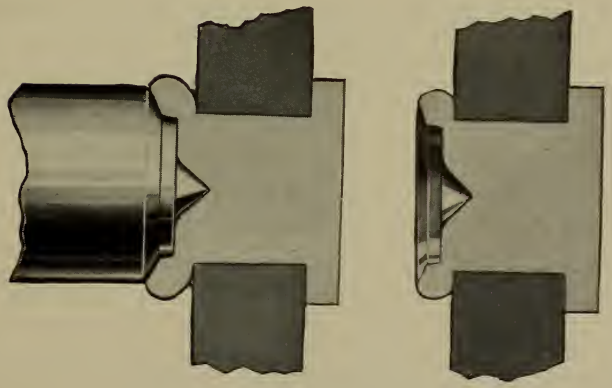

FIG. 2.—*Compressed terminal type*

under service conditions, the results obtained in general were poor. Moisture invariably found its way between the plug and the rail, or between the wire and the plug, thereby causing corrosion and an increasing contact resistance.

Channel pins and iron bonds still find a limited application on suburban tracks where the theft of copper bonds excludes that type, and where the rail and joint plates are of such dimensions as not to permit the use of concealed bonds. Under such conditions they are admittedly a makeshift and are employed only as a last resort and in the absence of any satisfactory method of bonding.

(*b*) SOLDERED BONDS.—With the failure of the riveted, bolted, and channel-pin bonds the necessity of a bond making a more perfect and permanent contact with the rail became apparent. The soldered contact early came into use to meet this demand and found universal adoption. With the exception of the most modern installations practically every electric railway company in the country has employed the soldered bond in one form or another. Its low cost and ease of application were in its favor and appealed to the operating companies. It can be applied to either the head, web, or base of the rail, requires no drilling, and can be installed without interruption to traffic.

The one serious objection to this type of bond is the difficulty in securing a permanent and low-resistance contact. The failures of soldered contacts are due to inherent defects in the method as well as to poor workmanship in installation. Copper has a coefficient of expansion nearly twice that of steel and somewhat less than lead-tin solder. It is evident, therefore, that with the diurnal temperature variations that steel rails undergo the soft film of solder connecting the two different metals is subjected to continual alternate strains which, in the presence of moisture and under the vibrations due to traffic, will eventually result in failure.

There are few mechanical processes in which the personal element enters so largely as in the application of bonds, and this is particularly true with respect to the soldered bond. As a rule, skilled mechanics are not employed for this work and the ordinary track laborer is slow in mastering the apparently simple feat of soldering a rail bond. In fact, he is a rare workman if he ever does learn the intricacies of this process and conscientiously ap-

plies his knowledge at all times. The soldered contact between bond and rail frequently corrodes without exhibiting any external signs of such deterioration. The bond might even resist a moderate blow from a hammer and still show a very high resistance when tested with a bond tester. Inspection therefore is not a reliable means of determining the condition of soldered bonds.

Another inherent defect of the soldered bond is the comparative ease with which it can be removed from the rail by copper thieves. A short bar is all that is necessary to remove these bonds from the head of a rail, and enormous losses of this type have occurred where the labor and time necessary to remove other types would have saved them.

While there are some engineers who still retain faith in the soldered bond, and a few companies employing well-trained and careful workmen continue to install them, their inability in general to meet the requirements of service have led to their abandonment by the majority of operating companies.

(*c*) Compressed Terminal and Pin-Terminal Bonds.—Compressed terminal bonds, shown in Figs. 2 and 3, are those having cylindrical terminals which are compressed with a screw or hydraulic compressor into holes drilled or punched in the web or base of the rails. They are referred to by the various manufacturers as compressed terminal, solid terminal, and compressed stud terminal bonds. Pin-terminal bonds are those having tubular terminals which are expanded into holes drilled or punched in the web or base of the rail by driving a steel pin into the hole in the terminal. They are referred to by the various manufacturers as pin-terminal, tubular-terminal, and pin-driven bonds. They will be referred to in this paper simply as pin-terminal bonds. The term "stud terminal" will be used to include both of the above types.

These bonds are made either in the solid, stranded, or ribbon type, and are designed either for concealed or exposed application. Although a great diversity of opinion exists regarding the merits of these bonds, they have found wide application and for more than 15 years have remained the standards for numerous companies. Owing to their wide use at the present time and in view of the general interest manifested by the companies in them,

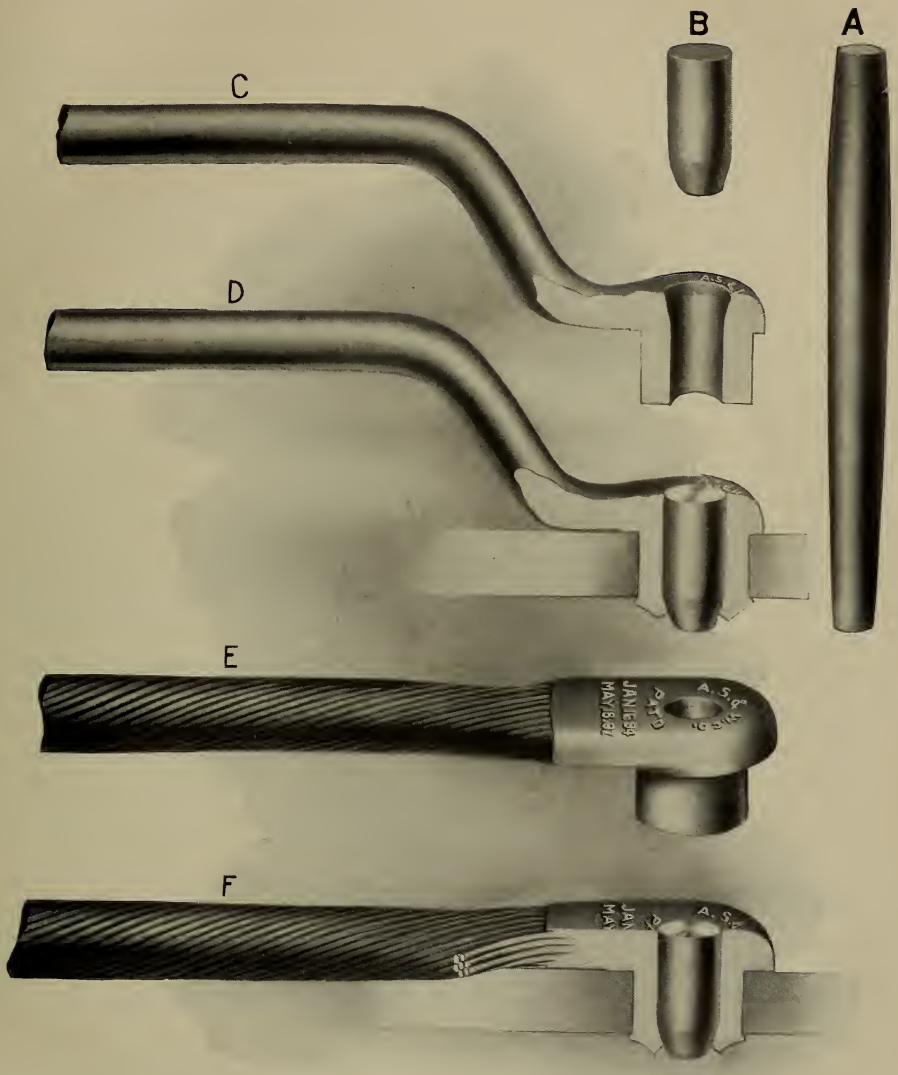

FIG. 3.—*Pin-terminal bonds*

a somewhat detailed account of their properties will here be in order.

Some difficulty was at first experienced by the manufacturers in securing a perfect union between the terminal and the strands or ribbons of these bonds. The successful welding of copper requires certain precautions in the exclusion of oxygen, and until improvements were made in their furnaces and methods the bond manufacturers found difficulty in turning out bonds with properly welded terminals. This defect has been entirely overcome, so that it is now possible to obtain bonds which are perfect in this respect. To overcome this trouble some manufacturers have forged the terminals from the wire strand of the bond itself.

Another improvement in the construction of stud-terminal bonds which has come into use only in recent years is that of machining the terminals. Before this practice was employed the inequalities in the stud made it difficult to obtain a perfect contact over the entire surface of the terminal. This gave a chance for the entrance of moisture between the copper and steel, with resulting corrosion and rapid deterioration. A film of moisture on the contact acts as an electrolyte, and with the passage of electric current rapid corrosion took place. A number of manufacturers now machine all bond terminals, while others do so only when specifications require it. The additional expense is small and most companies are willing to meet it for the increased life of the bond. Other improvements in the nature of annealing or softening the copper have added to the value of stud-terminal bonds by permitting a better flow of copper and consequently a better union with the steel.

Failure of the bond itself, due to the crystallizing and breaking of the wires and ribbons, has been largely overcome by increasing its length and by using a size of wires which experience has shown will withstand the maximum amount of mechanical vibration. Attention has also been given to the matter of forming bonds to conform to the joint plate and rail sections.

While the manufacturers have been active in their efforts to reduce the failures of the stud-terminal bonds, by introducing improvements and refinements in their methods of construction, the utility of these, as well as all other types of bonds, has been

greatly increased by improved methods in their installation. The importance of great care in the installation of stud-terminal bonds was, at first, not always appreciated by either the engineer or the workman. The many precautions and refinements now known to be imperative for best results were not known in the early days of electric railway engineering. Electric roads were springing up like mushrooms in every city. In many cases they were built by contract at so much per mile and concealed bonds received scanty attention. Indeed, cases are on record where bonds have been removed from such roads after a period of years and were found not to have been compressed or expanded at all but simply driven in the holes drilled to receive them and covered up by the joint plates. Bonds poorly installed frequently gave good service for a short time; sometimes for a few years. Even if they did not, the joint plates and the earth roadbeds frequently sufficed to return the current to the generators, and until water and gas leaks began to develop, or until the necessity for better service called attention to the poor return circuit, the bonds often received no consideration. It is little wonder, therefore, that years were required to establish the facts regarding the proper methods of bonding. The high percentages of failures that have been recorded in the past were apparently, therefore, on bonds which were manufactured and installed under conditions far different from those existing at the present time or even in recent years, and they can not be considered as an index to the performance of modern bonds installed under more favorable conditions.

Some of the features of installation which have contributed to the failure of stud-terminal bonds are here recounted: (1) The drilling of too large holes, thus requiring too great compression or expansion to make good contact. Holes are now usually drilled having the same diameter as that of the bond terminals. (2) Rough or irregular holes caused by dull or imperfectly ground drills. (3) Installing bonds in old, corroded, or wet holes. Bonds are now installed in only freshly drilled holes, perfectly clean and dry. (4) The use of oil in drilling. A film of oil between bond terminal and steel impairs the contact. Holes are now, as a rule, drilled dry. (5) Failure to clean web of rail around hole. Rust or scale on the web of the rail with which the face and button of

the bond comes in contact is likely to permit the admission of moisture to the contact. The best modern practice requires the grinding of the rail adjacent to the hole. (6) Incomplete compression or expansion of terminals. (7) Old or wrongly shaped compressor face. (8) Carelessness in driving expanding mandrel or pin. (9) Failure to clean bond terminal before installation.

As with the soldered type the personal element enters largely into the installation of stud-terminal bonds, evidence of which is given by reference to the numerous details recounted above.

The foregoing is considered a sufficient introduction to the discussion and comparison of the pin terminal and compressed-terminal bond which is to follow in connection with the reports of the operating companies.

(*d*) BRAZED OR WELDED BONDS.—This type includes all bonds in which either the copper terminal of the bond is welded directly to the rail or in which a third metal, such as brass or some other hard solder, is used to effect the union. Heat may be applied by any means, the most common being the passage of an electric current through the members being united, the electric arc, and the oxy-acetylene flame. The pouring of molten copper into a mold around the bond terminal has also been employed. The following definitions are in common use and will be adhered to in this paper.

Electric Weld.—Though commonly called a brazing process this term is used by the Electric Railway Improvement Co. in reference to the operation in which current passing through carbon electrodes in contact with the bond terminal generates the welding heat. It will here be employed in that connection.

Arc Weld.—A weld or brazing process affected by heat generated by an electric arc.

Oxy-Acetylene Weld.—A weld or brazing process affected by the use of the oxy-acetylene flame.

Copper Weld.—A weld or brazing process affected by pouring molten copper into a mold surrounding the bond terminal.

Up to the present time the use of the welded or brazed bonds has been confined almost entirely to that of the electric-weld type.

These bonds are more modern than the soldered and mechanically applied types described above, and their manufacture and

use has been greatly stimulated by the high percentage of failures attributed to the imperfect contacts of the latter-named types. A greater stimulus, however, was the growing need for a short exposed bond which could be applied to the head of the rail without removing the joint plates and which would make such tenacious contact as to discourage the attempts of copper thieves to remove it. The need for such a bond was so strong and the brazed or welded bond met the requirements so admirably that it at once sprang into extensive use, particularly on open track, even before time had demonstrated its lasting qualities. To guard against theft on suburban tracks and also to reduce its cost the bond was of necessity made comparatively short. This feature led to a rather high rate of failure from the breakage of the wires or ribbons, particularly on roads having poorly maintained rail joints. Imperfect methods of application and carelessness in installation also contributed to the failures of this type.

Like the stud-terminal bonds, therefore, the electric-weld bond had to go through an experimental stage. Improvements in construction, adoption of new types, as well as education of the railways in the methods of installation have progressed until to-day most of the early defects have been overcome and the bond is supplying a wide and growing demand.

The chief objections to the electric-weld bond are, first, as usually applied, their installation requires the purchase of rather an expensive bonding car, and, second, the bonding car is inconvenient to operate on tracks over which traffic is being maintained. The first objection is a serious one for small roads having limited means, and the second objection applies to all tracks on which the headway is of the order of 30 minutes or less. It is necessary to derail the bonding car to let regular trains pass, and this is obviously impracticable under a short headway. These objections are not pertinent to other types of welded bonds, and for this reason they are now making a strong bid for recognition.

Figs. 4 and 5 show two types of electric-weld bonds in common use. The ET type, which is the newer of the two, was recently designed to overcome defects in the EA type The manner in which the conductors of the EA type met and joined the bond terminal permitted of considerable bending and vibration at that

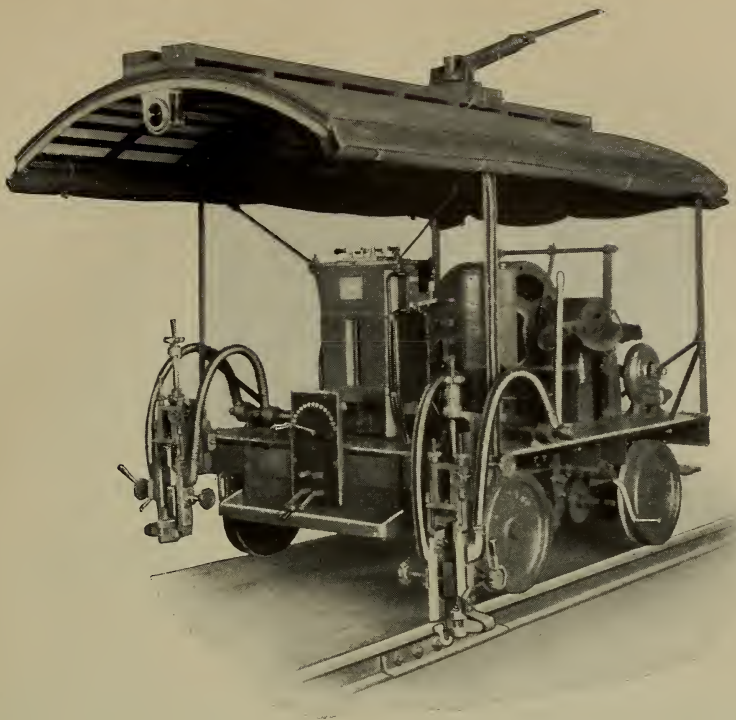

FIG. 6.—*Car for applying electric-weld bonds*

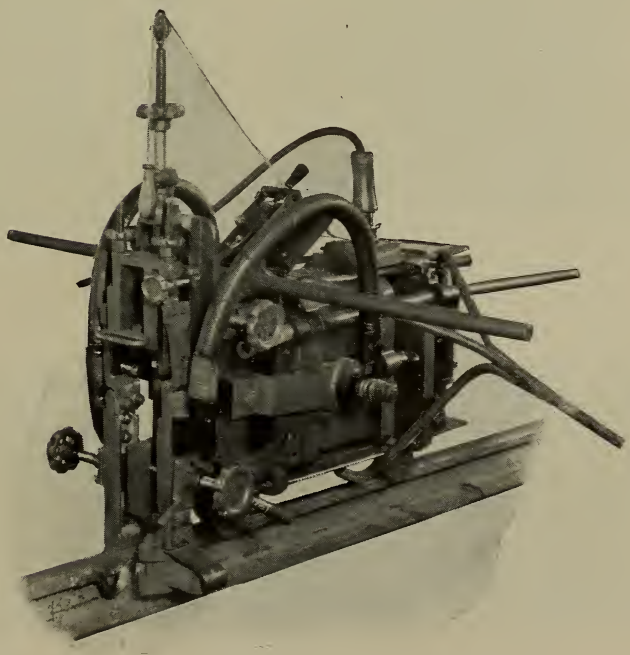

FIG. 6a.—*Portable welding transformer*

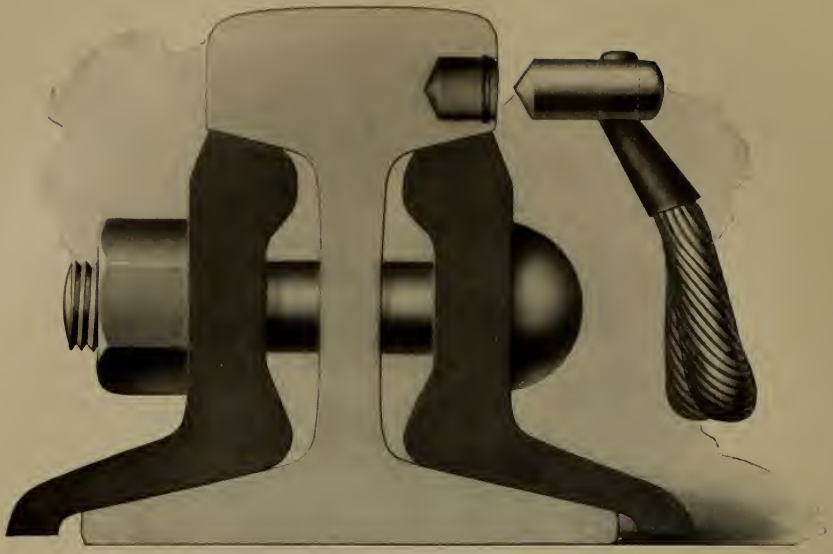

FIG. 7.—*Twin terminal bond*

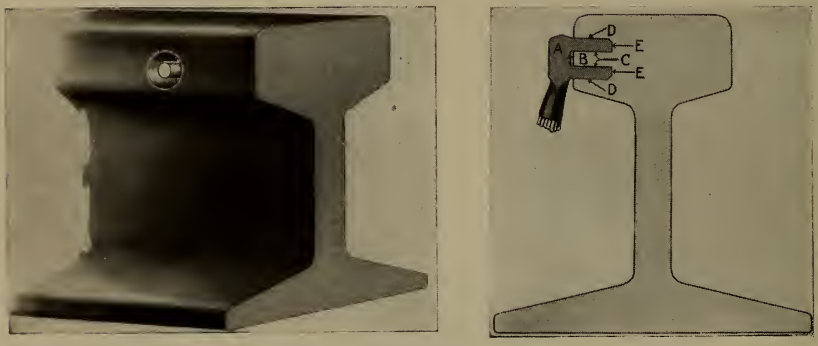

FIG. 8.—*Tubular terminal bond*

FIG. 9.—*Thermite weld*

point on poorly maintained joints and resulted in considerable crystallization and breaking of the ribbons. In the ET design the flexure is distributed throughout the entire length of the bond, thereby greatly reducing the failures from this source.

Where alternating current is available a portable outfit, shown in Fig. 6*a*, is employed. It is less expensive and more convenient to use than the bonding car.

(*e*) MECHANICALLY APPLIED HEAD BONDS.—Under this heading will be included the twin-terminal bond shown in Fig. 7 and the

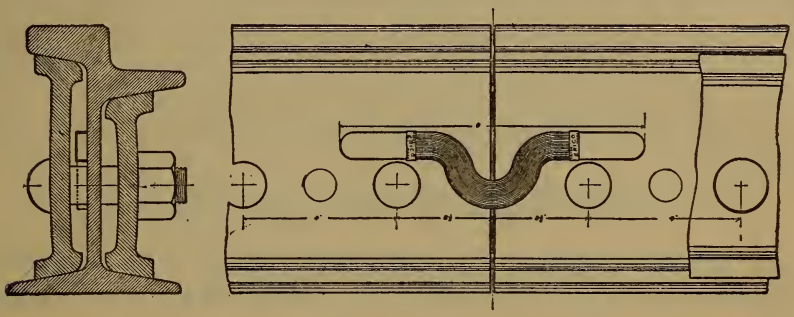

FIG. 4.—*Type EA electric-weld bond*

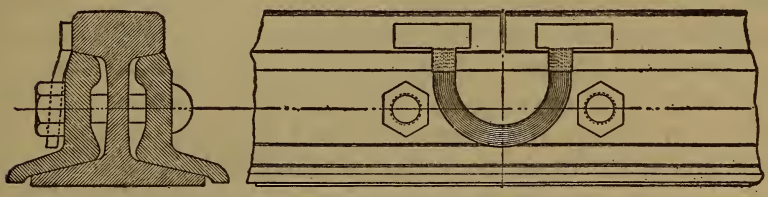

FIG. 5.—*Type ET electric-weld bond*

tubular-terminal bond shown in Fig. 8, both of which are short bonds applied to the head of the rail and used principally on suburban open track. The former employs two studs on each terminal about 1¼ inches apart which are driven into holes drilled in the head of the rail and upset, while the terminal of the latter type is tubular in form and is driven into an annular shaped hole milled in the head of the rail. Both types are short, comparatively inexpensive to install, make fairly good contact with the rail, can easily be inspected, and are relatively hard to steal. They may still be said to be in the experimental stage, however, and a

few more years will be required to demonstrate their ultimate utility.

(*f*) TUBULAR BONDS.—Recently a tubular copper bond has been placed on the market which is designed to join the web of the rail with the joint plates by expanding it into holes drilled through the three members at right angles to the length of the rail. It is about 4 inches in length and 1¼ inches in external diameter. At least two are required for each joint and more may be used This bond has not been in service long enough to demonstrate its utility, but as it is called upon to bear the joint strains incident to expansion and contraction its ability to maintain good contact with the rail and plates is very questionable. However, if installed on improved mechanical joints where bolt holes are reamed for a driving fit, it is possible that this bond would prove entirely satisfactory.

3. CROSS BONDING AND SPECIAL-WORK BONDING

(*a*) CROSS BONDING.—If all joint bonding could be maintained in perfect condition there would be no occasion for cross bonding of the two rails of a single track, although on double track the utility of cross bonding between tracks is obvious. As perfect bonding is an ideal condition, practically never realized, experience has shown the necessity of cross bonding both single and double track at frequent intervals. The function of cross bonds on single track is to shunt the current around poorly bonded or high-resistance joints, thereby tending to equalize the return current in the two rails. On double tracks they not only act as shunts around high-resistance joints but also act as equalizers between tracks which may not always be uniformly loaded. In the absence of cross bonds serious unbalancing of the return current is likely to result on poorly bonded tracks, which not only makes for excessive power loss and poor operation but introduces bad electrolysis conditions. Under extreme conditions it may also actually prove a life hazard to horses and pedestrians. A case is on record of a horse being thrown to the ground by bridging the two rails of a track. Actual test showed a difference of potential between the rails of 80 volts. The question of the intervals at which cross bonds should be installed is a pertinent one on which further discussion is to follow.

(*b*) Special-Work Bonding.—The problem of bonding special work offers some features not present on straight track. The joints are difficult to maintain, pounding due to traffic is excessive, frequently hard steel is used to which certain types of bonds can not well be applied, the sharp angles in frogs exclude the use of certain bonding tools, and the replacement of steel is more frequent than on straight tracks. Owing to these complications it has been found difficult to maintain good bonding through special work, and as a result it has become standard practice to bond around all such sections with heavy conductors. These are relied upon to carry the main current, and light bonding is usually installed to take care of the current originating in the section thus shunted out. Cables employed for this purpose can not be left exposed in unguarded regions as they offer particular temptation to copper thieves. Even when buried in the earth they are frequently dug up and removed by junk vendors.

4. WELDED AND SPECIAL JOINTS

With the advent of heavy electric traffic in paved city streets the bond and joint problem became acute. Both were found difficult to maintain and the repair of either entailed considerable expense in removing and replacing pavements. The rail joint was recognized as a weak link and the limiting factor in the life of their tracks by the operators; and when it was proposed to obliterate it by welding the joint, and was demonstrated to be a practical possibility, the idea was eagerly incorporated by many companies. Although the welded joint, like the rail bond, has had a somewhat checkered history and has met with many reverses and failures, it has grown in use until at the present time it is a standard of construction in some form or another in nearly every large city in the United States. The several types of welded and special joints which are now in service will be briefly described here, leaving a fuller discussion to the operating companies whose testimony is to follow later.

(*a*) Cast Weld.—This term is used in reference to an early type of weld, sometimes called the Falk joint, produced by pouring molten cast iron into a mold around the ends of the abutting rails, the latter having been cleaned by a sand blast or some other means.

In many cases it was not a weld at all owing to the difficulty in preheating the cast iron sufficiently to melt the steel of the rails. It was a good mechanical joint, however, and frequently served admirably the functions of both bond and joint plates. The many failures that occurred in this and other types of welds have been attributed to numerous causes. Whether the heating of the rail was sufficient to change its properties, and thereby result in excessive wear and breaks, has occasioned a great deal of discussion and is still a mooted question. Expansion and contraction has undoubtedly been responsible for failures in some cases, particularly where rails were welded in hot weather or laid in pavements having poor binding qualities. The cast weld is still doing duty in a number of localities, but in competition with other types, which are accomplishing the desired results in a more satisfactory manner, its installation has been practically abandoned.

(*b*) THERMITE-WELDED JOINT.—This is essentially a cast weld, but as the temperature attained by the reaction of aluminum and iron oxide is far in excess of that produced in the ordinary cast weld, the ends of the steel rails are melted down and an obliteration of the joint actually results. This method found early and wide application on experimental scales owing to the comparatively simple manner of obtaining a complete weld of the joint, but later it suffered a setback owing to the large number of joints which were found to cup after bearing heavy traffic for some time. In order to properly make the weld it was necessary to leave a space of about three-quarters of an inch between the rail ends and fill in with the molten metal. As it was practically impossible to duplicate the physical properties of the rail a soft spot was left which eventually gave rise to cupping. Recent improvements have eliminated this defect, however, and the joint is again finding favor with the railways. It requires much less metal than the old cast weld, and has a high conductance. It is better adapted for new than for repair work, as the process is difficult to carry out under traffic conditions. A completed weld is illustrated in Fig. 9.

Thermite welds have also been used in connection with mechanical joints. A shoe of thermite steel is poured around the base of a bolted or riveted rail joint, thereby welding the base of the

FIG. 10.—*Electrically welded joint with head support*

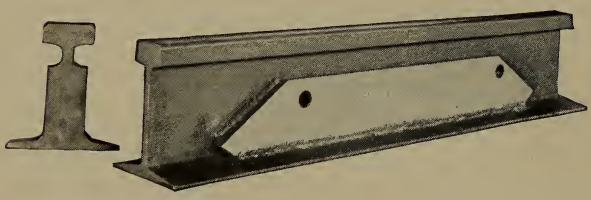

FIG. 11.—*Arc welded joint*

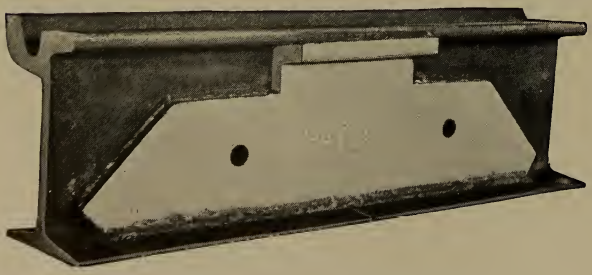

FIG. 12.—*Arc welded joint with head support*

rail but in no wise changing the properties of the head or running part. The joint needs no other bond and is mechanically good. It has met with marked success in Baltimore and Cleveland, where it is known as the "Clark joint."

(*c*) ELECTRICALLY-WELDED JOINT.—The electrically-welded joint was introduced over 15 years ago and has found wider application than any of the other modern types. It consists of heavy bars or plates from 2 to 3 feet in length spot welded to the web of the rail by the use of an electric current. The process requires a heavy and expensive plant and is usually carried out by contract on a comparatively large scale. For this reason it is not well suited to installations on small systems. It is well adapted to the reclaiming of old track as well as for new work and has been applied on open T-rail construction where expansion joints are installed at intervals to provide for expansion and contraction. Fig. 10 shows a section through the center of an electrically-welded joint with head supports.

Failures of this type of weld have in general been confined to fracturing of the rail at the end of the welded bar and are no doubt the result of strains introduced into the web of the rail from the localized heating. Such breaks have been more prevalent in old than in new rails. On new work with rails having no bolt holes the failures have been reduced to a minimum, which is not considered serious.

(*d*) ARC-WELDED JOINT.—This term will be employed in reference to joints in which the plates have been welded to the rail by means of an electric arc. The method is comparatively modern and is just emerging from the experimental stage. The features which appeal to the operating companies are ease and simplicity of application, low cost, and high conductance. In the most recent types the rails are not heated to an injurious degree.

This method of welding has also been applied to the welding of rails to steel ties and also to the welding of bolted and riveted joint plates to the base of the rail. This latter process provides for a joint of high conductance, strengthens it mechanically, and eliminates any possible danger from heating the web and head of rails. The recent adoption of this process for welding joint plates by numerous companies after a trial installation is strong evi-

dence of its utility for this purpose. Two improved types of welded joints are shown in Figs. 11 and 12.

(*e*) THE NICHOLS COMPOSITE JOINT.—This joint consists of two plates which fit the web of the rail and are riveted snugly to it but which do not come in contact with the fishing surfaces. The spaces thus left around the head and foot of the rail are filled with molten zinc, which expands upon solidifying and enters into all of the irregularities of the rail surface. If the rail and plates are properly cleaned before pouring the zinc, a good electrical contact is obtained and a joint of high conductance is the result. The process is rather expensive, and is warranted, therefore, only on lines bearing heavy traffic. The fact that it has been a standard of construction in the city of Philadelphia for a number of years is an indication of its practicability.

(*f*) MECHANICAL JOINTS.—In recent years a number of companies have gone to some pains and expense in the construction of bolted and riveted joints designed to eliminate the effects of expansion and contraction, which in the ordinary bolted joint often results in looseness and ultimate failure. Where bolts are used, the holes are drilled undersized and carefully reamed out to give a driving fit. Machine bolts with square heads are used and an accurate shop fit is obtained in the field. Rivets are sometimes substituted for bolts. In some cases the plates are drilled short and heated to make the holes meet. When they shrink, the ends of the rails are drawn together with a great force and trouble from cupping is thereby largely eliminated. Such mechanical joints as here described, when carefully bonded, possess the best features of the welded joint and are free from some of the latter's defects. It is obvious that they can not be used in other than paved streets unless some provision for expansion and contraction is made.

III. COMPILATION OF INFORMATION SUBMITTED BY OPERATING COMPANIES

1. QUESTIONS SUBMITTED AND NATURE OF REPLIES

Before asking for information or opinions from any of the operating companies, a thorough study of the bond and rail joint problem was made by a careful reference to all trade literature

available, by correspondence with manufacturers, and review of the technical literature of the subject.

After obtaining a fair knowledge of the problems involved and the present practices employed, a circular letter and list of questions were prepared for distribution among the operating companies. The letter called attention to the lack of uniformity among the operating companies in their bonding practices and the need for cooperation in an effort to better solve the difficulties connected with the problem. It asked for a free discussion of the subject and for individual opinions rather than a reply confined to the answering of definite questions. This letter, together with a copy of the questions, was mailed to a list of 130 operating companies selected from every State of the Union, made up for the most part from the larger companies, although a number of companies operating railways in cities of from 15 000 to 40 000 population were included.

Following is a list of the questions submitted:

RAIL BONDS

1. What types and sizes of rail bonds have you used? State whether soldered, brazed, welded, compressed, or expanded terminal bonds; whether solid, stranded, or ribbon; whether concealed or exposed; to what part of the rail attached; number and length of bonds per joint.

2. On what type of construction has each type of bond been used? Give weight of rail, length of rail, type of rail, type of splice bars, type of roadbed, kind of pavement adjacent to rails, character of traffic.

3. About how many of each type and size of bond have you in operation at the present time?

4. Do you inspect your bonds regularly? If so, how, and how frequently?

5. Do you have a definite criterion for determining when a bond requires replacing? If so, what is it?

6. About what is the average life of each type of bond? Give the percentage of failure for each year after installation.

7. At what intervals do you cross bond the two rails of each single track; also the two tracks on double-track construction?

8. On what basis do you determine the size of cross bonds to be used?

9. Do you bond around all special work?

10. What type of bonds do you use for cross bonding and special-work bonding?

11. To what extent have you been troubled with theft of different types of bonds?

12. What grade of labor do you employ for the installation of different types of bonds, skilled or unskilled?

13. What special tools and machinery do you employ in the installation of different types of new bonds; also, in the repair of bonds?

14. Do you use a lubricant in drilling for compressed or expanded terminal bonds?

15. Are your drills machine or hand ground?

16. What is the complete cost of installing each type of new bond when installed in large numbers; also, of renewing a bond? State in detail how costs are computed. (The total cost of installing a bond should include the cost of the bond, the cost of the tools, the interest and depreciation on the tools and machinery, supplies, electric energy if used, labor, and paving repairs.)

17. What is the most prevalent cause of failure of each type of bond?

18. What is the average resistance in terms of rail length, or in ohms, of each type of bonded joint when new and when old?

WELDED AND OTHER TYPES OF RAIL JOINTS

1. What types of rail joints, and how many of each type, have you in operation at the present time?

2. On what type of construction has each type of joint been used? Give weight of rail, length of rail, type of rail, type of roadbed, kind of pavement adjacent to rails, and character of traffic.

3. What is the average efficiency of each type of joint, i. e., its electrical resistance compared to an equal length of rail? Give length of joint used in testing.

4. About what is the average life of each type of joint? Give the percentage of failures for each year after installation.

5. What is the total cost of each type of joint on new work? What is the cost of replacing a joint which has failed? (See note to question 16 under "Rail bonds.")

6. What is the most prevalent cause of failure in each type of joint?

7. What are the maximum and minimum temperatures to which your welded joints are subjected?

8. With what types of joints and under what conditions do you use expansion joints in your rails?

In answer to the above inquiries, 42 companies, or 32 per cent of those addressed, submitted replies. This percentage, although not large, was considered as satisfactory and encouraging. The mileage represented in the replies was about 8600 miles of single track and represents nearly 20 per cent of the mileage in the United States. The constant demand upon public-service corporations from outside sources for statistics and information has assumed such proportions that it is little wonder that a large number of them have been disregarded altogether. Information is sought by engineering committees, colleges, State and city commissions, Government bureaus, and private engineers, and unless accompanied by an authoritative request such communications frequently are pigeonholed or find their way into the wastebasket. The generous number and the nature of the replies received, as well as the apparent willingness on the part of the companies to cooperate with the Bureau in its investigation, were complete vindication for the attempted study. The attitude

of the companies toward the matter is illustrated by the following statement from L. P. Crecelius, superintendent of power for the Cleveland Railway Co. and president of the engineering association of the A. E. R. A. for the year 1914–15.

> We agree in the suggestion that a study of the question of rail bonds is very important. Examination of the practice in regard to rail bonds reveals a wide difference in opinion as regards both the type and character of rail bonds and the method of applying them. We consider the subject not only important, but timely, and take pleasure in replying to your circular letter requesting cooperation.

With but a single exception the answers were submitted in good form, and the majority of them showed considerable labor in their compilation. A few replies showed the marks of a hasty and cursory survey of the subject, but these constituted only a small minority.

Below is given a list of the companies and their equivalent single-track mileage from whom replies to the circular inquiry were received. They are listed and numbered in the order in which the replies were received, and hereafter, for the sake of brevity, will be referred to by number rather than name. The mileage here given was taken from the McGraw Electrical Directory of August, 1915:

		Miles.
1.	Union Electric Co., Dubuque, Iowa	21
2.	Ohio Electric Railway Co., Springfield, Ohio	617
3.	Indianapolis Traction & Terminal Co	158
4.	Milwaukee Electric Railway & Light Co	403
5.	Dallas Consolidated Electric Street Railway Co	50
6.	United Railroads of San Francisco	280
7.	Helena Light & Railway Co	24
8.	Scranton Railway Co	100
9.	Puget Sound Traction, Light & Power Co., Seattle, Wash	499
10.	Connecticut Co., New Haven, Conn	171
11.	United Railways & Electric Co. of Baltimore, Md	405
12.	Houston Electric Co	75
13.	Spokane, Portland & Seattle Railway Co	240
14.	Chattanooga Railway & Light Co	61
15.	St. Joseph Railway, Light, Heat & Power Co	49
16.	Harrisburg Railways Co	72
17.	Omaha & Council Bluffs Street Railway Co	140
18.	Metropolitan Street Railway Co., Kansas City, Mo	265
19.	Memphis Street Railway Co	124
20.	Tacoma Railway & Power Co	104
21.	Everett Railway, Light & Water Co	17
22.	Butte Electric Railway Co	35

	Miles.
23. Terre Haute, Indianapolis & Eastern Traction Co.	101
24. Louisville Railway Co	150
25. San Francisco-Oakland Terminal Railways	256
26. Portland Railway, Light & Power Co., Portland, Oreg	299
27. Minneapolis Street Railway Co	435
28. Pacific Electric Railway Co., Los Angeles, Cal	1,057
29. Los Angeles Railway	383
30. Omaha, Lincoln & Beatrice Railway Co	56
31. Birmingham Railway, Light & Power Co	154
32. United Railways Co., St. Louis, Mo	442
33. Interborough Rapid Transit Co., New York, N. Y	167
34. Rhode Island Co., Providence, R. I	399
35. New York Central & Hudson River Railroad Co	254
36. United Traction Co., Albany, N. Y	103
37. Cleveland Railway Co	344
38. Peoples Railway Co., Dayton, Ohio	31
39. Pennsylvania Railroad Co	99
40. Cleveland Southwestern & Columbus Railway Co., Cleveland, Ohio	225
41. Philadelphia Western Railway Co., Upper Darby, Pa	50
42. Washington, Baltimore & Annapolis Electric Railroad Co	100

Realizing that the information obtained from formal replies to a set of questions could be greatly strengthened and its value enhanced by personal interviews with the engineers of a number of companies a representative was placed in the field for that purpose. His itinerary included Harrisburg, Baltimore, Philadelphia, New York, Boston, Buffalo, Cleveland, Cincinnati, Indianapolis, Louisville, Richmond, and about 20 other intermediate cities and towns. During his five weeks' tour he interviewed upward of 50 electric railway engineers and visited a number of manufacturing establishments.

The information obtained on this tour, while not abounding in figures and percentages, forms a valuable supplement to the carefully prepared and conservative statements and tabulations contained in the formal answers and will be included when possible in the summations which are to follow.

Owing to the large number of questions asked and to the nature of the answers the material does not well lend itself to a condensed tabulation. Little could be gained by such a summary owing to the indefiniteness of the replies and the fact that they consist largely of estimates and opinions.

A more satisfactory presentation of the data and the one which will be employed is a tabulation of figures, facts, and opinions

under the several questions asked, to be followed by an analysis of all available data, with recommendations, under the various types of bonds, joints, and methods in use.

As the amount of material collected is so large as to preclude it from publication in full, summaries will be made where practicable. On points of particular interest and on which a lively difference of opinion exists or on which opinion has not yet crystallized the information as received will be given in full.

While there is, of course, no thought or desire of injuring or depreciating any product of any manufacturer, a frank and impartial discussion of all materials and methods is essential to the best results of the investigation. Such discussion, it is believed, will not injure any standard product or method, but, on the other hand, will benefit the manufacturers in helping the companies to standardize on certain products, thereby relieving the factories from continuing the manufacture of the great variety of types that are now demanded by the trade.

2. COMPILATION OF DATA SUBMITTED BY OPERATING COMPANIES ON BONDS

(*a*) QUESTIONS 1, 2, AND 3. NUMBER AND TYPES OF BONDS.—These questions ask for the sizes and types of bonds which have been used, for the type of construction on which each type of bond has been used, and for the number of each type in use at the present time.

In answer to the first question a majority of the companies enumerated a number of types of bonds as having been used in the past and stated that most of the early types had been replaced by modern bonds. The following answer from the Louisville Railway Co. is given to show the great variety of bonds which have been employed since the early days of electric railway engineering and serves admirably as an historical sketch of the development of the practice as well as an example of the experimental efforts which the roads have resorted to in their attempt to suitably bond their tracks.

LOUISVILLE RAILWAY CO. (MOTIVE POWER DEPARTMENT)—RAIL BONDS

A. No. 6 bare tinned copper wire bent around a $\frac{3}{8}$-inch copper rivet in each end and placed outside of splice. On some occasions soldered to a continuous wire of same size running along the track; used about 1889.

B. 4/0 Chicago bond, solid type, used outside of splice bar, rivet driven in from back; used 1894, 1895, and 1896.

C. 4/0 solid crown bond adopted in 1897; used outside of splice. Steel drift pin driven in from front.

D. In same year tried on 2 miles of track the Bryan and brass washer, bolted type, using two pieces of 1/0 trolley or two pieces of 4/0 insulated.

E. Used in 1899 and 1900, 300 4-inch protected bonds (4/0 flexible), which were put on with screw compressor—T rail. They were too short to allow for contraction and were replaced a few years later by 12-inch crown bonds.

F. 300 000 c. m., 500 000 c. m., and 1 000 000 c. m., cable "Buffalo" bonds, cast-brass terminals threaded for nut, bolted, soldered, and tinned on web of 9-inch girder rail; 1899 to 1901.

G. 8½-inch to 12-inch flexible (4/0) crown riveted bonds used under Atlas and continuous joints on T-rail track, interurban and park line 1902 to 1907.

H. Adoption of same type on 9-inch girder rail.

I. 68-inch and 61½-inch solid (4/0) crown riveted cross bonds.

J. Previous to this cross bonding had been done by soldering continuous wire to stubs.

K. Adoption of solid terminal, compressor type, except where compressor could not be used around special work, short bonds flexible, long ones solid; 1908.

L. Installation in 1910 of exposed brazed ribbon bonds outside head of rail on 40 miles 70-pound T track; interurban. Found large number of these bonds broken in succeeding years, partly due to loose and low joints.

M. A trial in 1910, on one side of 6½ miles of an interurban line 1000 of the American Steel & Wire Co.'s twin terminal type; 75 per cent stolen in 1913–14 and the rest removed.

N. Returned in 1913–14 to 4/0 crown flexible compressor type under continuous joints on all open track.

O. Cross bonding on 70-pound T rail in country by pieces of 70-pound rail turned upside down, welded to base of running rail every 1000 feet, during 1914.

P. Welding 300 or more pairs of splice bars (1914) on 7-inch and 9-inch girder rail, city construction, using Indianapolis arc welder.

Q. One bond to each joint is used on 60-pound or 70-pound T rail or old light girder rails. One, two, or three bonds each joint on 7-inch or 9-inch girder rail in the city, according to headway of cars.

R. All bonds attached to web of rail except in items L and M, which were attached to rail heads.

Expanded bonds, A, B, C, D, G, H, I.

Compressed bonds, E and K.

Soldered bonds, F.

Standard type bonds, G, H, K, M, N.

Question 2, as to the type of construction on which each type of bond had been used, was not asked so much with the idea of determining what bond is best suited to a given type of construction as to determine, if possible, the causes of reported bond failures. In a few instances the answers lend themselves

to such interpretation and will be employed in the discussion of that subject.

In answer to the third question 36 of the 42 companies gave some figures as to the number of bonds in use at the present time. In some cases their figures were not complete, but were given for only one or more types of bonds in use or for bonds installed since a given date. The number of bonds reported, therefore, is only a fraction of the total number represented by the 36 companies answering this question, but nevertheless undoubtedly give a fair indication of the relative number of each type that has been installed in recent years throughout the country.

The 2 305 300 bonds reported are classified as follows:

Compressed terminal:	
Ribbon, concealed	214 200
Stranded, concealed	338 100
Stranded, exposed	176 300
Not described	201 000
Total	929 600
Pin terminal:	
Stranded, concealed	241 100
Stranded, exposed	63 200
Not described	58 500
Total	362 800
Electric weld:	
Exposed	392 600
Concealed	27 400
Not described	300 000
Total	720 000
Soldered, all kinds	140 800
Twin terminal	113 700
Oxy-acetylene, welded	15 000
Channel pin	20 000
Plastic alloy	3 400
Total	292 900
Grand total	2 305 300

These figures show that among the companies reporting the use of compressed-terminal bonds is in excess of that of any other type, with the electric-weld bond second.

For concealed application the stranded bond is a favorite over the ribbon type, the percentages being 61 and 39, respectively, in the compressed-terminal type, while no concealed-ribbon bonds of the pin-terminal type were reported.

The largest number of bonds reported was 315 000 by Company 28. Of these 300 000 are electric-weld and include both head and web types, the relative numbers not being given.

The second largest number of bonds reported was 243 000 by Company 35. Of these 81 000 are soldered bonds on third rail and 162 000 pin-terminal, stranded bonds. Company 6 reports the use of 199 500 bonds, 196 000 of which are said to be compressed terminal. They no doubt include all varieties of that type and are listed as "not described." Of the 720 000 electric-weld bonds in use 300 000 were reported by Company 28 and 160 000 by Company 2, and of the 113 700 twin-terminal bonds 60 000 were reported by Company 11. The 15 000 oxy-acetylene-welded bonds are used by Company 27. The two million bonds and more reported are sufficient to single bond 30-foot rails on 6550 miles of single track. As this is about 75 per cent of the mileage represented by the answering companies, it is safe to assume that a large percentage of bonds in use were reported.

(*b*) Question 4. Inspection of Bonds.—Forty-two answers to this question are briefly summarized as follows: Fifteen companies do not inspect bonds regularly; 6 companies test bonds by inspections and melting snow only; 2 companies test bonds every 3 months; 10 companies test bonds every 6 months; 12 companies test bonds every 12 months; 1 company tests bonds every 18 months; 3 companies test when bonds are apparently in bad condition; 4 companies employ an autographic-recording bond-testing car; 23 companies employ some kind of portable bond tester; and 1 company tests exposed soldered bonds with a hammer.

These figures indicate that all degrees of inspection and testing are employed from the observance of joints around which snow is melting to frequent tests with accurate instruments. While the majority of the companies aim at regular inspection and testing, numerous interviews revealed the fact that such aims are not always realized. Testing is frequently done by men who have other regular duties to perform and who give their time at irregu-

lar intervals to this work, and this time may not always be sufficient to comply with the standards set by the company. Moreover, in times of financial stress this feature of maintenance is frequently considered as unnecessary and is consequently slighted. Even were it carried out, the funds for following up the replacement of poor bonds are not always available.

Several companies state that the condition of exposed bonds is determined by inspection only, instrument tests being confined to concealed bonds. While bonds can be quickly inspected by trackwalkers this does not always give assurance of their good condition. Mechanically applied and soldered bonds frequently develop high resistances when no indication of such is apparent from inspection. A hammer blow gives a better indication of conditions, but of course is not always infallible.

It should be pointed out that failure to test bonds regularly and systematically is not always an indication of carelessness or unconcern on the part of an operating company. A test of bonds is of little value unless followed up by repair. It frequently happens that a systematic repair of bonds, as a bonding proposition only, is not justifiable owing to the fact that a general rehabilitation of the system may be in progress or in contemplation, which in the course of a very few years would weld or otherwise repair all joints. Under such circumstances a company might not be justified in repairing any but the very worst joints, and these as a rule can be detected either by inspection or by melting snow. This condition while not often existing over an entire system is frequently met with in limited areas or regions, where it becomes necessary to maintain an old track for from one to three years to await the city's order for change of grade or for repaving. A general repair of bonds under such circumstances might not be advisable, and again only open joints would receive attention.

(*c*) QUESTION 5. CRITERION FOR REPLACEMENT.—Upon this point widely varying standards appear to be in practice. Twenty-six companies of the 42 have a definite resistance below which they aim to maintain all joints, the resistance being defined in terms of equivalent length of adjacent rail. Other roads bond only when joints are open or bonds are broken, or where snow is found

to be melted. The summary following is compiled from answers submitted to question 5.

TABLE 1

Criterion for Bond Replacements

Number of companies	Criterion for replacement (3 feet of joint equal to feet of rail shown)		Number of companies	Criterion for replacement (3 feet of joint equal to feet of rail shown)	
	City	Suburban		City	Suburban
	Feet	Feet		Feet	Feet
1	3½	.....	1	8	27
2	3¾	.....	2	9	.....
1	4	.....	2	10	.....
1	5	.....	2	10	.....
5	6	.....	1	15	.....
1	6	12	2	20	.....
2	7	.....	6	(a)	.....
2	8	.....	9	(b)	.....
1	8	12			

[a] Open bond or melted snow, or when 50 per cent of strands are broken. [b] No answer.

Joints showing a resistance of 4 feet of rail or better are, as a rule, bonded with two or more bonds, and are confined for the most part to heavy traction lines such as exist in New York City. The average value of the figures for city streets is 8.3 feet.

(*d*) Question 6. Average Life of Bonds.—The answers to this question are so vague and inconsistent and the failure of bonds are affected by so many conditions and circumstances that it is difficult to draw definite conclusions from them. The fact that the life of a bond depends in a large measure upon the life of the joint was brought out by a large number of the answers. Few figures and statistics giving percentages of failures and the life of various bond installations were submitted. The question is one of such great importance and the answers of so much interest that a number of them are here quoted.

Company 3.—The brazed type of bond shows a failure of 2 per cent, which is caused by loose rail joints, and is not charged against the bond. The compressed type shows no failures chargeable to bonds. * * * Where the failures of compressed type of bonds may appear unreasonable, we have no record of this type of bond failing in the past 10 years other than due to rail breaks or where joint becomes so loose that it

would gradually break the strands and separate the bond. All of our bond terminals are carefully tinned before compressing in the rail. We take particular pains in grinding our drills so as to make a smooth, clean hole in the rail, and also keep the bond compressor in good condition so as to get an even compression on the bond terminal. We have kept this practice up for 10 years and find that it is giving excellent results, and we now figure the life of a bond longer than the life of the rail.

This company uses stranded bonds and continuous splice bars.

COMPANY 4.—We have approximately 34 000 soldered leaf bonds on our open track. Of these about 3500 were replaced in 1912, about 2200 in 1913, and about 5100 in 1914. Our records do not show the percentage failure by years after installation.

COMPANY 5.—The life of a bond we have found to be determined entirely by the life of the joint, i. e., so long as the bolts remain tight and the joint in good service, just so long will the bond be good. In nearly all cases where defective bonds have been removed it has been found that the joint itself was loose and by its vibration the bond would become detached from the rail or at least become loosened.

This company employs stranded pin-terminal bonds.

COMPANY 6.—The life of a bond depends almost entirely upon the rigidity with which the rail joint is maintained. With an absolutely unmovable practically homogeneous rail joint one bond would last about as long as another and all would last until the rail was worn out. Data about "average life" of bonds would be misleading. Such data has not been kept. Our experience has taught us to prefer short expanded terminal, concealed, ribbon bonds where permissible.

Company 7 uses twin-terminal soldered bonds and renews them when they show a resistance greater than 15 feet of rail. In answer to question 6 they say:

COMPANY 7.—The average life of the bond is about 6 years. Nearly all of the failures were either due to poor workmanship in putting them on, or to the loosening of the splice bars which allowed a movement of the rails to break the strands of the bond.

COMPANY 8.—We have no data on which to base the probable life of the different types of bonds. It has been our experience that the mechanical condition of the joint fails before the bond. Consequently the failure of the bond is then due to the poor mechanical condition of the joint. Should the joint be maintained in good mechanical condition and the bond is properly installed, cases have been noted where the bond did not show any depreciation after 8 to 10 years of service. These instances are rare, for the reason that the mechanical condition of the joint usually requires attention before that period, and the bond is also replaced.

From our experience the life of the exposed bond is greater than that of the concealed type, probably due to the fact that the mechanical condition of the track is usually better.

COMPANY 10.—The life of the bonds, we find, vary from 3 to 12 years. The percentage of failures can not be stated at this time.

COMPANY 11.—Twin-terminal and compressed-terminal bonds usually last as long as the track, the percentage of failure is very small. The percentage of failure of soldered bonds is extremely high; we have no definite figures.

COMPANY 12.—The average life of these bonds is about 6 years.

This company uses stranded concealed pin-terminal bonds.

COMPANY 13.—Our soldered bonds, after 7 years, are practically all off, and 50 per cent of them were off in half that time. Our experience with these bonds has been that the few bonds which we were able to get on properly gave excellent results, but on the average it was impossible to get these bonds so soldered to the rail that they would stand under heavy traffic.

At the present time our interurban lines outside of the city, consisting of about 150 miles, are virtually all bonded with the welded bonds.

We aim to make an inspection of our bonds at least once a year. Our trouble with the welded bonds has been the breaking of the leaves of copper just below the lug which is welded to the rail. This is doubtless due to the weakening of the metal through heating at the time the weld is made. Vibration and the deflection of the joint tend to work the leaves till eventually they snap off close to the lug. We have endeavored to overcome this by having the bond people furnish us with a welded bond with the terminal in the shape of a T, so as to overcome any bending of the leaves by deflection at the joint. We have not had these experimental types of bonds on long enough to tell whether the cure is going to be effective.

In the case of the pin-terminal bond, the only trouble experienced has been the loosening of the terminal by reason of incomplete expansion when driving the pin. These bonds have to be very carefully put on or they will work loose under the plates. The compressed-terminal bonds have given us better satisfaction in this respect.

The following table, giving percentage of failures for various types of bonds, is extracted from the report of Company 14:

TABLE 2

Company 14. Bond Failures

Kind of bond	Between rails	Percentage of failures	Years since installation	Length in miles under consideration
4/0-10-inch, compressed	Brick	23	1	1
4/0-10-inch, compressed	Asphalt	39	1	½
4/0-13-inch, compressed	do	22	1	1
4/0-36-inch, compressed	Wood block	69	1	1
4/0-10-inch, compressed	Macadam	30	1	1
4/0-10-inch, compressed	Brick	4	2	1½
4/0-13-inch, compressed	Open	20	2	6
4/0-10-inch, compressed	Brick	6	3	2
4/0-10-inch, compressed	Asphalt	39	3	1
4/0-10-inch, compressed	Macadam	19	3	3
4/0-10-inch, compressed	Open	46	3	7½
4/0-10-inch, compressed	Brick	3	4	2
4/0-10-inch, compressed	Asphalt	4	4	½
4/0-36-inch, compressed	Macadam	35	4	½
4/0-10-inch, compressed	Open	19	4	4½
3/0-10-inch, compressed	do	39	4	1½
4/0-36-inch, compressed	do	24	5	½
4/0-10-inch, brazed	Brick	3	5	3

COMPANY 16.—The life of a bond depends almost entirely upon the type of track construction. In first-class construction, such as we use in paved streets, we never have a broken bond, and the depreciation is confined to a slight corrosion of the strands, and in a few cases a corrosion of the terminals. The latter only occurs where the bond has not been properly applied.

In open-ballast construction, expansion and contraction of the rail must be allowed for in the joint. This, with defects in track construction, such as loose bolts, poor foundation, etc., causes the strands on the bonds to break. On suburban lines the record for the year 1914 is as follows:

Number of joints tested	Defectives		Type of joint	Weight of rail	Age of installation
	Number	Per cent			
				Pounds	Years
2590	29	1.1	Weber	65	8
1454	40	2.75	Channel	65	10
2086	74	3.50	.....do	56 and 65	20
364	28	7.8	.....do	60	14
1182	64	5.5	Continuous	70 and 85	7

COMPANY 17.—Up to the present time we have noticed no failure of the brazed bonds.

COMPANY 19.—Bonds will last indefinitely if rail joints are kept in good repair.

COMPANY 22.—No record. If the bond is correctly installed and the rail joint is perfect, I see no reason why the bond should not last as long or longer than the rail.

COMPANY 23.—I am unable to state what is the average life of each type of bond, but in my opinion the short bond attached to the head of the rail will, as a rule, last 3 to 6 years and the larger compressed-terminal bond around the splice will have an average life of approximately 12 years. The life of all bonds depends entirely upon the track conditions. If it were possible to keep the joints absolutely tight under all conditions it is quite possible that the life of the bond, especially of the longer type around the splice, would be equal to the life of the rail.

COMPANY 24.—Brazed bonds, 7½ years; compressed bonds, 15 years.

Company 25 submitted a table showing the cause and rate of failure of about 10 different sizes and types of bonds. All types show a high rate of failure with the exception of the compressed terminal, installed with mercury alloy, which shows no depreciation. This type, however, is the only one used on paved streets with concrete roadbed, and this type of construction no doubt has more to do with their good performance than the type of bond itself.

COMPANY 26.—Can not state average life of bonds. The failure of compressed-terminal bonds has been very light, probably not 2 per cent in six years; on twin-terminal bonds would estimate 5 per cent failure in five years. The soldered bonds have been unsatisfactory. We have found it impossible to maintain them in good condition.

COMPANY 27.—We find that all pin-terminal bonds, expanded in holes in the rails, after a comparatively short life of low resistance begin to blacken at contact, with resulting high resistance within one year after installation. We find that with soldered terminals the solder disintegrates either from vibration or electrolytic action, and that within one or two years a high resistance results. This is also true where heavy lugs are soldered onto the rails for the purpose of connecting cables.

COMPANY 29.—Ten-inch compressed-terminal ribbon bonds have been in service over 10 years; no trouble from breakage. All concealed bonds have an average life of from 5 to 15 years, depending upon maintenance of plate bolts from loosening up.

COMPANY 31.—The life of a bond depends more on the condition of the rail joint than any other feature. We have never kept any records that would give us actual life of bonds under various conditions, but we believe that in our recent concrete paving construction, where we desire rail joints tight and pay special attention to their installation, the life of the bonds will equal the life of the rail and paving, which will be from 10 to 25 years, depending on the quantity of traffic. We believe further that on some of our old track of 56 and 60 pound rail, either in open work or chert paving, where the rail joints are very bad, the life of the bond is probably only a few months, or at least one year.

COMPANY 33.—On account of the fact that the life of the bond in a track rail is contingent on the life of the rail, and as the life of this track rail is comparatively short, due to the high frequency of service and the heavy car mileage, an estimate of the average life of the bond would not be reliable and might be misleading.

Regarding the life of bonds on the contact rail, would advise that except in isolated instances the bonds show no appreciable deterioration after a life of 12 years.

COMPANY 34.—In 1899 about 6 miles of 70-pound, 60-foot rail, single track, was laid in country road, dirt ballast, bonded with two 36-inch, 4/0 stranded bonds with expanded head. Tested 8 years after installation, showed no defective joints. Tested 15 years after installation, showed about 4 per cent defective joints.

In 1901 about 30 miles of single track was laid in country roads with 70-pound T rail, 60 feet long, bonded with one 8-inch and one 17-inch, 4/0 concealed bond with expanded head, around each joint. These bonds were tested in 1914 and showed about 4 per cent defective.

In 1904 about 21 miles of single track was laid with 9-inch girder rail, 60 feet long, 98 pounds per yard, gravel ballast, and block and macadam paving. Bonded with two 12-inch ribbon, 4/0 bonds, with compressed heads. Tested in 1907, no defective joints; tested in 1914, showed about 5 per cent defective joints.

In 1913 we rebonded somewhere over 5000 joints on 60 and 70 pound T rail, 30 and 60 feet long, with 9-inch 300 000 c. m. ribbon bonds welded to ball of rail. Tested in 1914, no defective joints.

COMPANY 35.—Average life of bond not yet determined. Percentage of failures: 1909, 0.15 per cent; 1910, 0.069 per cent; 1911, 0.082 per cent; 1912, 0.064 per cent; 1913, 0.047 per cent; 1914, 0.098 per cent.

This company uses pin-terminal stranded bonds.

COMPANY 36.—I can not give you definite information as to the average life. In 1913, 0.86 per cent of bonds were replaced; 1914, approximately 0.1 per cent.

This company uses pin-terminal stranded bonds of various lengths.

COMPANY 37.—Life of bonds has been found to depend very largely upon the type used and its exposure to vehicle traffic, tampering, and theft. A loss of 2 per cent as failures in brazing rail bonds to the rail we have found to be an average figure and as representing the failures due to defective brazing, which, however, are checked up and corrected as the work progresses and such defects are made good. The brazes show a remarkably effective life, and failures seem to take place in the breaking off of the strands next to the terminal. Our experience for the last few years indicates that a thousand bonds per year become defective because of theft, mutilation by vehicles, and breaking off of strands at the terminal, or based upon the total number of bonds we have in service this is approximately 1.5 per cent loss per annum. We have bonds in service which were brazed to the rails 10 years ago.

COMPANY 38.—Over 30 miles of track which has been installed from the year 1894 to the present time the percentage of failure you will find as follows: Special work—open, 235; defective, 81; main track—open, 181; defective, 129; giving figure of merit, 87.8.

These figures were derived from autographic records recently made by bond-testing car.

COMPANY 39.—The average life of each type of bond varies in our installation. The exposed type of bond is used in tunnels and station area, and in three years we have had to renew 65 bonds, or about 0.4 of 1 per cent of the total number installed in these sections.

Of the concealed type we have had to renew 1200, or about 5 per cent of the total number of bonds installed. The large renewal is confined to one section, which is on built-up ground where high speed with heavy traffic loosens the joints. We have also found that in some cases the splice bars squeeze the strands of the bonds and they eventually break off. This of course is not due to defects in design and manufacture of bonds. The percentage of failures for the first year was less than 1 per cent, and for the past two years was a little over 0.1 per cent, and for the last year was about 2 per cent.

COMPANY 40.—About 5 per cent of the solder type of bond will need replacing at the end of first year and about 20 per cent at end of second year, after which the depreciation is much faster. We do not believe that the average life of installation of solder bonds will run much over 3 years.

The average life of the pin-terminal type of bond is from 4 to 6 years; the depreciation of contact, however, is very marked before the elapse of this period. The resistance increases about a third at end of first year and has about 50 per cent more resistance after the third year than at installation, while at the end of the 4 years, besides the increase in resistance, we have found about 40 per cent of bonds out of rail.

The welded bond shows no increase in contact resistance during our 11 years of use. If joints are not kept tight, failures will occur, due to strands breaking. It is hard for us to set a percentage of failure, for we have found that on lines where the track is kept in good condition the bonds have not depreciated in any way. Up to the present time we have replaced about 1 per cent of these bonds a year, due to joint depreciation, theft, and careless workmen.

COMPANY 41.—Practically all of the compressed bonds are giving good service after 9 years of operation, the life of the road. Have had some trouble with electric-welded bonds due to faulty installation during construction.

COMPANY 42.—Since our company began operation, February, 1908, from the maintenance standpoint we have replaced 7357 bonds.

This is on an installation of 33 000 twin-terminal bonds and amounts to 3 per cent per year.

(*e*) QUESTION 7. INTERVALS FOR CROSS BONDING.—The following figures show the intervals at which the companies cross-bond in city streets:

	Feet
2 companies	100 to 200
4 companies	300
16 companies	500
4 companies	600
10 companies	1000
1 company	1500
2 companies	3000

As a rule these figures apply to both single and double track, although four companies bond the two tracks on double-track construction at greater intervals than they do the two rails on each track. Eight companies cross-bond open and suburban track at greater intervals than city track. One company employs no cross bonds, owing to the use of block signals. Two companies install cross bonds directly beneath trolley feed taps in order that they may easily be located at any time.

(*f*) QUESTION 8. SIZE OF CROSS BONDS.—With but few exceptions the companies appear to have no other than an arbitrary basis for determining the size of cross bonds. Twenty-one of the 42 answering use 4/0 copper exclusively, while 11 proportion their cross bonds to accord with the load on the rails and the distance from the power house. One company cross bonds with copper 20 per cent greater than the combined capacity of feeders and trolley.

(*g*) QUESTIONS 9 AND 10. BONDING AROUND SPECIAL WORK.—With but a single exception the 42 companies use supplementary copper around their special work in addition to bonding through it. The type of bond terminal used for this and cross bonding is with nearly all companies the same as that employed on their straight work, extra lengths of copper being soldered to the terminals when needed. A few roads using compressed-terminal bonds on straight work resort to pin-terminal bonds on special work, owing to the difficulty of using a compressor in the sharp

angles of the frogs. With regard to this feature, Company 3 states that they now order their frogs with an extra foot of rail, thereby permitting the use of the compressor in all cases.

(*h*) QUESTION 11. THEFT OF BONDS.—Thirty-four of the 42 companies report the loss of bonds by theft in varying extents. With 16 of these the trouble has been chronic, while with 18 it has been slight or infrequent. It has been much more serious on soldered bonds than on other types, owing to the comparative ease with which these can be removed. Cross bonds and jumper bonds have been stolen in great numbers, even where they were buried in the earth. On open construction the only way of safeguarding long bonds appears to be to concrete them in. One company reports that after losing many cross bonds this method of protecting them was resorted to and so incensed the thieves whose revenue had thus been eliminated that they cut and mutilated the bonds at the terminals, apparently for spite. Theft of copper is not confined to bonds, but trolley wire and even No. 8 ground wires have been known to disappear overnight. Company 40 reports that in the past 11 years 350 welded bonds and 3500 soldered bonds have been stolen. Company 42 states that in 7 years 800 twin-terminal bonds have been stolen, the total number installed being 33 000. These are the only roads giving definite figures on theft of bonds.

(*i*) QUESTION 12. GRADE OF LABOR FOR BONDING.—The question as stated is ambiguous, owing to the different interpretations placed on the words "skilled" and "unskilled." With some companies a skilled laborer is one who has had considerable experience in applying bonds, although he may not have had training as a machinist. With other companies only experienced mechanics would be considered as skilled. In view of the existence of this ambiguity, the answers received to this question do not always give a definite idea of the grade of labor employed.

The following brief summary of the answers is given with no attempt at interpretation: Fifteen companies use skilled laborers; 10 companies use unskilled laborers; 8 companies use a skilled foreman and unskilled laborers; 7 companies use experienced laborers; 2 companies use skilled laborers for welded bonds and unskilled laborers for mechanically applied bonds.

(*j*) QUESTION 13. BONDING TOOLS.—As the answers are not complete, it is impossible to say how many companies use the hydraulic and how many the screw compressor, or to what extent power drills are used in preference to hand drills. No summary of answers to this question will be attempted.

(*k*) QUESTIONS 14 AND 15. DRILLING.—Twenty-one companies use no lubricant of any kind in drilling holes for bonds, 4 use water only, 8 use soapy water, 2 use lime or soda water, 3 use oil, 19 roads grind drills by hand, and 13 roads grind drills by machine.

(*l*) QUESTION 16. COST OF BONDING.—The cost of bonding is extremely variable, depending upon the locality, the price of copper, whether holes are punched at factory or drilled on the job, whether joint plates are applied by bonding gang, whether work is new or repair, whether traffic interferes or not, and upon a great many other factors. As average values, therefore, would have little significance, no attempt at tabulation of bonding costs will be attempted. A few specific quotations giving conditions under which the work was accomplished will be of much more value and are therefore given in this form.

Company 2 gives the following unqualified figures:

10-inch 4/0 compressed terminals	$0.65
8½-inch 4/0 electric weld	.50
36-inch 4/0 welded to web	.95
8-inch twin terminal	.55

Company 4 gives the cost of—

Standard leaf bonds, soldered	$0.45
250 000 cir. mils cross bonds soldered	2.00

COMPANY 5.—Cost of installing one 9-inch flexible-crown pin-rail bond we estimate as follows:

Bond	$0.40
Labor	.30
Tools	.05
Total	.75

COMPANY 6.—Compressed terminal, new work. Holes drilled at factory:

Labor	$0.04
Bond	.417
Miscellaneous	.0045
Total	.4615

COMPANY 7.—Operating full day, installing twin-terminal bonds:

Bond	$0.35
Labor	.15
Gasoline and solder	.03
Miscellaneous	.0035
Total	.5335

TABLE 3

Company 8. Bonding-Installation Costs

Rail where bond was applied	Head		Web		Head		Web					
Type of bond	Brazed to head	Twin ter.	Comp ter.	Pin ter.	Brazed to head	Twin ter.	Comp or pin ter.	Brazed to web	Comp ter.	Pin ter.	Comp ter.	Pin ter.
Length of bond (inches)	8	Reg.	10	10	8	Reg.	10	40	40	40	10	10
Size of bond	4/0	4/0	4/0	4/0	4/0	4/0	4/0	4/0	4/0	4/0	4/0	4/0
Cost of bond	$0.33	$0.36	$0.46	$0.46	$0.33	$0.36	$0.46	$0.80	$0.80	$0.80	$0.46	$0.46
Labor cost (installing bond)	.10	.06	.10	.08	.17	.17	.25	.25	.25	.20	.25	.20
Labor cost, removing and replacing splice bars	.....	.....	.....	.....	.....	.....	.40	.....	.....	.....	.40	.40
Labor cost, paving	.....	.....	.....	.....	.....	.....	.....	.40	.60	.40	.50	.50
Paving materials	.....	.....	.....	.....	.....	.....	.....	.60	1.00	.60	.80	.80
Interest and depreciation on tools and appliances	.07	.001	.02	.02	.07	.001	.001	.07	.02	.02	.002	.002
Cost of electrical power	.02	.002	.002	.002	.02	.002	.....	.02	.002	.002	0	.....
Joint material	.....	.....	.....	.....	.....	.....	.20	.....	.....	.....	.20	20
Miscellaneous supplies and expense	.02	.026	.01	.01	.02	.026	.01	.01	.01	.01	.01	.01
Total cost	.54	.449	.592	.572	.61	.559	1.321	2.15	2.682	2.032	2.622	2.572

COMPANY 11.—Cost of installing twin-terminal bonds in quantities 11 cents to 15 cents each, exclusive of cost of bond. Cost of installing pin or compressed terminal bonds where holes are only reamed, 25 cents per joint where two bonds are installed.

COMPANY 13.—The cost of installing the welded bond is about 20 cents each, exclusive of cost of bond, renewals under traffic about 36 cents, and cross bonds 64 cents. The latter are placed on the web of the rail.

COMPANY 14.—Total cost of installing thermo bonding 100 new 36-inch 4/0 bonds in open track:

100 new 4/0, 36-inch compressed bonds	$82.46
Labor, drilling and applying new bonds, 2 men and 1 foreman, 3 days	20.00
25 pounds thermite, at 30 cents	7.30
½ pound powder, at $1.25	.63
Cost of tools and depreciation	2.00
Total cost	112.59
Cost per bond	1.13
100 new 10-inch 4/0 compressed bonds in open track, itemized as above (per bond)	.76
(Cost of rebonding with 36-inch, 4/0 compressed bond same as for new work, with credit of $0.105 per bond for scrap.)	
Cost of rebonding exposed track with 10-inch 4/0 compressed bond (each)	.89
Scrap credit (each)	.07
Net cost (each)	.82
Cost of rebonding around joints in brick pavement 10-inch 4/0 compressed bonds (each)	1.04
Scrap credit (each)	.07
Net cost (each)	.97

COMPANY 16.—Total cost per joint of double bonding with 4/0 compressed-terminal concealed bonds itemized as follows:

Two 4/0 bonds	$0.80
Labor drilling holes, applying bonds, and plates on 7 and 9 inch rail	.50
Depreciation at 15 per cent and interest at 5 per cent on $500 equipment equals fixed charges per year, $100.	
On basis of 700 joints per year	.14
Electric current, miscellaneous supplies	.06
Total	1.50
Same for T-rail construction	1.42

COMPANY 17.—The average cost of installing a 9½-inch brazed bond, inclusive of paving, is $0.6392. The labor costs are from records of 5710 bonds installed in 1913 and 1914. The highest labor cost was $0.85 per bond. This was at a point where four bonds only were installed and the traffic was heavy, so it was necessary to do this work at night. The lowest cost of labor per bond was $0.10, which was on open track where the service could be kept off most of the day. The cost of opening and replacing pavement is $0.25.

The following figures are from Company 20 and are based on 1000 bonds installed. All types are soldered bonds:

	Each.
38-inch cable bond	$0.3567
Type B. B. bond in paving	.59
Type A, 750 M c. m	1.59
Horseshoe bond	.46
Type C twin terminal soldered	.808
B. B. bond open-track work, includes removing and replacing plates	.66
38-inch Clark 500 M c. m. bond	1.94

Company 23.—Our cost for installing 19 818 electric-weld bonds in 1912 was as follows:

Labor per bond	$0.13004
Material per bond	.3138
Total per bond	.44384

This does not include interest and depreciation of bonding car and tools nor cost of electric energy used.

The cost of labor for the compressed-terminal type bond will average from $0.50 per bond on new work to $1.25 per bond on old work. The cost depends largely upon the work required in taking up and replacing pavement.

Company 25.—(1) Single bonding, 70-pound A. S. C. E. rail, 4/0, 10-inch, compressed-terminal bond, no traffic, bond holes punched, electric current not used, joints in large numbers.

Labor:	
Removing and replacing angle bars	$0.08
Reaming bond holes	.07
Alloying bond holes	.04
Compressing-bond terminals, painting and adjusting	.109
Total	.299
Superintendence	.03
Tools, 2 per cent	.006
Material:	
One 10-inch bond	.363
Alloy	.05
P and B No. 1 paint	.012
Total	.425
Store expense, 2 per cent	.008
Total cost per joint	.768

(2) Double bonding, same as (1), $1.445 per bond.

(3) Single bonding, reconstruction, 141-pound P. S. Co. No. 263 rail, 450 000 cir. mil., ribbon compressed-terminal bond, bond holes punched, traffic under 20-minute headway, electrical energy not used, joints in small numbers. Itemized as above, $1.261 per joint.

(4) Single bonding, repairs, oiled macadam pavement, 70-pound A. S. C. E. rail, 4/0, 10-inch, compressed-terminal bond, holes not punched, traffic under 10-minute headway, electrical energy not used, track fastenings in good condition, joints in small numbers. Itemized as above, $1.38 per joint.

(5) Single bonding, repairs, asphalt pavement, same as (4), $1.971 per joint.

(6) Double bonding, same as (4), $2.21 per joint.

COMPANY 26.—Compressed-terminal, soldered 9-inch bond, $0.55; labor, $0.35; solder and gas, $0.10; total, $1. Twin terminal, $0.42; labor, $0.22; total, $0.64, exclusive of paving charges.

COMPANY 27.—Complete cost of installing oxy-acetylene-welded bonds of 250 000 cir. mils capacity in large numbers is between 50 and 60 cents per bond, including cost of tools and machinery.

COMPANY 31.—Brazed bonds, $0.56 in quantities; $0.70 to $1.55 for renewals. Compressed terminal, $0.69 in quantities; $0.75 to $2.30 for renewals.

COMPANY 32.—The cost of bonds given herewith includes the cost of the bond and the labor of installation for open-track work. A good many of the bonds are made in the company's shops, and the copper cost at which they are figured is 14 cents per pound. No interest and depreciation on the cost of tools used is taken into account, as these figures reduced to a per bond basis are considered negligible. This also applies to the cost of power.

72-inch compression bond	$1.25
39-inch compression bond	.95
33-inch compression bond	.90
22-inch compression bond	.75
22-inch head-compression bond	.40
Twin terminal	.61
9 inch crown, concealed	.98
7-inch soldered	.65

Company 33 submits the following table:

TABLE 4

Company 33. Bonding Installation Costs

Size of bond	Form of copper	Length	Number per joint	Roadbed	Cost per joint
		Inches			
4/0 (one joint)	Strand exposed	40	1	Elevated	$2.30
4/0 (one joint)	do	46	1	do	
300 000 cir. mils	do	23	2	do	1.99
300 000 cir. mils	do	26	2	do	
425 000 cir. mils	Strand semiconcealed	18	4	do	5.08
550 000 cir. mils	Ribbon exposed	5½	2	Ballast	1.98
400 000 cir. mils	Ribbon concealed	12	2	do	2.04
400 000 cir. mils	Strand concealed	12	2	do	2.04
300 000 cir. mils	do	9	4	do	3.04
300 000 cir. mils	Ribbon concealed	9	4	do	3.04
437 675 cir. mils	Solid concealed	3⅜	4	Elevated	2.48

Company 35 states that the labor cost of installing a pin-terminal bond is 35 cents. This figure is significant when considered in connection with the table giving percentage of failures on this road. More will be said later regarding the methods employed by this company in installing pin-terminal bonds.

Company 38.—Installing new bonds, large quantities:	
Drilling and reaming $\frac{27}{32}$-inch holes	$0.05
Compressing bond	.05
One 9-inch bond	.40
Electric current	.06
Depreciation	.05
Total	.61
Renewing bonds in pavement:	
One 9-inch bond	$0.40
Six T bolts	.24
20 paving bricks	.40
Cement and sand	.10
Electric current	.02
Labor	1.68
Depreciation	.28
Total	3.04

Company 40.—300 000 cir. mils solder bonds cost us 63 cents to install in large numbers and about 40 cents each on renewals.

The pin-terminal bonds cost us approximately $1 each to install in large numbers and about $1.75 each on renewals. The renewal price covers labor in taking off and putting back plates and using one-half new bolts.

The electric-weld bonds cost us 43 cents each to install on renewals. The above prices include all labor, current used, supplies, and the interest and depreciation on the tools and apparatus. No paving charges are included.

Company 42.—Twin-terminal bond: Bond, 35 cents; labor and tools, 15 cents; total, 50 cents.

(*m*) Question 17. Causes of Failure.—The companies are almost unanimous in stating that the principal cause of bond failures is vibration, resulting from loose rail joints. Two companies have given corrosion as the chief cause of failures while five state that many bonds fail from external causes, such as traffic and injury from workmen. Other causes of failure enumerated are expansion and contraction and poor workmanship.

The following characteristic quotations are selected from answers submitted to question 17:

Company 5.—The only cause of failure of pin-terminal bonds is either defective installation at the start or the loosening of bolts and the vibration of the joint.

COMPANY 8.—From our experience the causes for the failure of rail bonds have been twofold: (1) Improper maintenance of the mechanical condition of the rail joint, and (2) carelessness on the part of the laborer in the installation of the bond in question.

Our experience has been that 70 per cent of the defective bonds requiring renewal will be found at rail joints, whose mechanical condition is very poor. This has given the conclusion that a large percentage of bond failures is due to the poor mechanical condition of the joint.

Carelessness in the installation of the bond is brought about in several ways: (1) Imperfect drilling of the hole; (2) not wiping the hole clean of the lubricant used for the drill; (3) not cleaning the terminal of the bond thoroughly; (4) improper use of the bond press or other tools for installing the bonds; (5) crushing the bond between the splice bars and rail, when the splice bars are installed, and in the case of the brazed bond, "burning the bond" by allowing the welding or brazing temperature to become too high and thus making a poor contact between the bond and rail.

COMPANY 15.—The causes of failure are usually two. The contact corrodes or the rail splits through the bond hole. Frequently a split rail is shown up by the bond testing before any sign of split is seen at the head of the rail except probably the joint is a little loose.

COMPANY 20.—We have had only about five failures with the type C twin-terminal soldered bond since we started using them and in all cases failures were due to ballast becoming wedged between the bond and the rail and a defective wheel forcing the rock down and destroying the bond.

COMPANY 22.—Many compressed-terminal bonds have become loose in the rail through electrolytic action caused by poor contact. Have had no trouble of that kind with pin-terminal bonds. Most of our bond failures have been due to broken bonds, caused by joint working.

COMPANY 24.—Brazed bonds are often too short and break when the joints become low or slightly loose. Compressed-type concealed bonds: (1) Due to loose joint; (2) splice plate binding bond; (3) poor installation, not having bond terminal bright and not compressing terminal enough or too much.

COMPANY 28.—We have found that the principal cause of failure on all bonds other than the brazed has been on account of poor contact. With the brazed bonds, however, the contact remains perfect and failure only occurs when the bond breaks.

COMPANY 30.—Soldered bonds crack off from contraction of rail or from weather conditions. Stranded compressed-terminal bonds pinch and break at the end of the rail.

COMPANY 39.—The most prevalent cause of failure of concealed bonds is breaking of strands due to excessive vibration. Some other causes are: (1) Terminals broken by hammer blow of repair man; (2) strands broken by being squeezed by splice bar; (3) strands burned by accidental short-circuit of third rail; (4) strands broken by replacing of bolts in splice bars. In exposed bonds failures have been very rare and are included in (1) and (3) of above causes.

COMPANY 40.—(*a*) We find that the solder bonds fail due to the fact it is hard for even an experienced operator to obtain uniform results in installing. After installation, the action of the current seems to crystallize and deteriorate the solder, causing the terminals to drop off. The mechanical union between the bond and the rail is not of sufficient strength so as to prevent bonds being knocked off with a hammer and stolen. The strands break, of course, on loose joints.

(*b*) Pin-terminal bonds fail due to the corrosion of the terminals and the loosening of the same and strands breaking on loose joints. We believe that the corroding of the terminals is hastened in a new installation due to the fact that it is almost impossible to drill holes in the rail of an absolutely uniform size. This is also hastened by the unequal coefficient of expansion of the copper and steel during temperature changes.

(*c*) Electric-weld bonds fail by strands breaking on loose joints. We have had very few failures due to poor workmanship, and have had no terminals depreciate or drop off when properly installed.

COMPANY 41.—It has been our experience during the six years of service on this property that, with the use of the compressed-terminal concealed bonds, drilling the holes in the web of the rail, making a total of four holes in the end of each rail, weakens the rail at this point to such an extent that any undue strain brought to bear on this point will cause the rail to break. Have had eight breaks in the six years, and with the exception of two have always found the fracture followed down through one of the bond holes.

(*n*) QUESTION 18. RESISTANCE OF BONDS, NEW AND OLD.—Information on this point is somewhat meager and inconsistent. Only a few companies were able to give figures, and these are quoted below:

COMPANY 7.—A new twin-terminal bond will equal about 3 feet of rail, when the old ones will average about 4½ or 5 feet.

COMPANY 8.—The average resistance in terms of rail length for the different types of bond joints is rather an indefinite figure, due to the number of variables that enter into same. A joint newly bonded with a 4/0 bond will have a resistance equivalent to approximately 3 to 6 feet of adjoining rail, depending on the size of the rail. In about two years this will increase to about 5 to 8 feet, remaining constant at that amount for about six or eight years, when its resistance increases rapidly.

COMPANY 11.—With reference to twin-terminal and compressed-terminal bonds, we have found no difference in resistance between old and new bonding, so long as the bonds remain unbroken and their terminal contacts are unimpaired.

COMPANY 14.—The average resistance of new compressed-terminal bond is about 6 feet of rail. The average resistance of an old compressed bond is about 13 feet of rail. The resistance of brazed bonds after being installed five years is about 5 feet of rail.

COMPANY 16.—Our experience has been that there is very little change in the resistance of a bond if properly installed. As an example will give the results of a test made within the last 10 days.

The piece of track on which the test was made was constructed in 1907. Weight of rail, 85 pounds; car service, 10-minute intervals; construction, concrete ballast with subballast of crushed rock; average current per rail, 300 to 400 amperes.

The results of the test show the drop in millivolts on 24 joints, including 3 feet of rail, as compared to the drop on the 3 feet of adjacent rail. The figures range from 10 to 15 for the solid rail and from 10 to 18 for the joint. The average resistance of the 24 joints is about 10 per cent greater than that of 3 feet of solid rail.

The joints are bonded with two 400 000 cir. mils bonds per joint. The copper equivalent of these rails is about 850 000 cir. mils. We do not have on record the

readings on the joints when new, but considering the amount of copper in the joint and the copper equivalent of the rail we do not believe the resistance of the bonds could have changed but very little during seven years of service.

Our experience in compressed-terminal bonding indicates that the essentials for good results are to have the holes drilled of uniform diameter, free from all traces of any lubricant, bond terminals machine finished, in order to assure a driving fit; finally, the maximum amount of compression possible with tools available for this class of work.

COMPANY 19.—We consider that two 4/0 compressed-terminal bonds with a continuous rail joint has the equivalent resistance of 4 feet of 70-pound rail when new. Age does not affect this if the track joint is kept in good condition.

COMPANY 26.—Tests of compressed-terminal bonds and twin-terminal bonds are practically the same, 4 to 4½ new, 5 to 6 when old.

COMPANY 34.—Two 36-inch 4/0 bonds, pin-terminal, on 60-pound T rail, when new resistance equals 8 feet of rail. When in six years, resistance equals 10 to 12 feet of rail. Compressed terminals show about the same resistance.

COMPANY 35.—Average resistance of pin-terminal bonds on track rail equals 18 to 20 inches new, 36 to 40 inches old.

COMPANY 37.—In the use of brazed bonds there is a remarkable similarity between the resistance of the bond when first applied and when old, which indicates the great advantage of this type of bond over all others.

COMPANY 40.—(*a*) The 9-inch 300 000 c. m. soldered bond when first installed on 70-pound rail equals 8 feet of rail. We lose about 5 per cent of the bonds during the first year, and about 20 per cent the second year.

(*b*) The 10-inch 4/0 pin terminal when first installed on 85-pound tee rail equals 7½ feet of rail. The same bonds are equal to 9½ feet of rail at the end of first year, about 10½ feet of rail at end of third year, while at the end of four years we have found 40 per cent of the bonds out of the rail.

(*c*) The short 4/0 electric-weld bonds are equal to 4.9 feet of rail when first installed and have shown no terminal depreciation during our 11 years of use.

3. COMPILATION OF DATA SUBMITTED BY OPERATING COMPANIES ON WELDED AND OTHER TYPES OF RAIL JOINTS

Of the 42 companies enumerated heretofore but 17 employ other than bolted joints, and the data submitted by these roads apply for the most part to old types of welds which are now either practically obsolete or which have recently been so modified and improved that records of failures during the past years are unreliable and misleading as an indication of the performance of modern welded joints. Unfortunately, but few of the larger traction companies whose experience would be most valuable on this subject are included in the list of those answering our circular, and while many of these have been visited and interviewed regarding their experience with rail joints, very little in the way of statistics from them is at hand for tabulation.

It is obviously unwise to generalize or base conclusions and percentages on data compiled from so few as 17 reports, representing as they do but a small percentage of the total mileage equipped with welded joints. The tabulations and quotations which follow, therefore, should be considered as representing special rather than average conditions. They will, however, be used in a later part of the report in connection with material obtained from other sources as the basis for some general conclusions and recommendations.

(*a*) QUESTION 1. *Number of joints in use.*—Table 6 gives the total number of welded as well as bolted joints reported by the several companies answering, as well as the number of companies reporting the use of each type of joint.

As with the bonds, only a fraction of the total number of joints represented have been reported, owing apparently to the lack of records. The questions on welded and other types of joints were intended to cover only electrically continuous joints. Nine companies, however, gave figures on bolted joints as well, which accounts for the comparatively small number reported.

TABLE 5

Number of Rail Joints Reported

	Number in use	Companies reporting use		Number in use	Companies reporting use
Electrically continuous joints:			Bolted joints—Continued.		
Cast welds	149 716	10	Bonanza joints	.....	3
Thermite welds	46 849	7	Duquesne joints	2 147	3
Electric welds	11 697	5	Bonanzo and Duquesne	20 000	.....
Arc welds	1 300	4	Atlas	.....	2
Clark joint	50 000	2	100 per cent joints	2 000	1
Nichols joint	8 490	1	Angle bars	159 402	.....
			Channel bars	32 671	.....
Total	268 052	.....	Fish plates	9 336	.....
Bolted joints:			Total	301 925	.....
Continuous joints	68 669	19			
Weber joints	7 700	3			

(*b*) QUESTION 2. TYPES OF CONSTRUCTION.—With but few exceptions welded joints have been installed only in city paved streets with concrete or stone ballast. A few companies report the use of welded joints in macadam or earth streets and one on open track.

(*c*) QUESTION 3. ELECTRICAL EFFICIENCY OF JOINTS.—Ten companies reported the efficiencies of their welded joints to be 100 per cent or better. One company gave the efficiency of cast welds to be 67 per cent. Six companies had no data on this question. The electrically-welded joint was reported by various companies from 100 per cent to 170 per cent efficient, electrically.

(*d*) QUESTIONS 4 AND 6. LIFE OF JOINTS AND CAUSES OF FAILURE.—The following quotations, taken from answers to questions 4 and 6, are given in preference to a summary which would not be satisfactory:

COMPANY 3.—Our experience shows that the life of our rail on good track is from 15 to 20 years under our ordinary traffic conditions, say one 20-ton car every 3 or 4 minutes per 18 hours. On this type of track 95 per cent of our 5000 cast-welded joints have lasted the entire life of the rail. The electrically welded joints have been in only two years. We shall be disappointed if 95 per cent do not last the life of the rail.

Where the continuous rail joint has been applied we had no renewals for the first two years. From the third to the fifth year about 20 per cent of the joints required renewal. At the end of 10 years the renewal was total; that is, all of the joints had been renewed. With ordinary splices under the same traffic conditions as those under which the continuous joints were used, all of the splices had to be renewed within five years.

The above is an opinion in the absence of absolute data, but is in a general way correct.

The usual cause of failure in every joint is the deflection of the joint due to the load, causing an ultimate pounding of the joint. The final result is a cupped place on the receiving rail and looseness due to wear, the wear being on the fishing surface of both the rail and the splice. This is true for every type of joint.

When rail is first welded either electrically or by means of cast weld about 1 per cent of breaks will occur within the first 60 days. We expect such breaks and consider them necessary to permit the rail to adjust itself to conditions, and the repair of these breaks should be included in the cost of the first installation of the welded joint.

COMPANY 4.—The average number of cast-weld joints replaced in repairs each year is about 1000, the total number of joints in service being about 42 000. A great number of joints were taken out when tracks were replaced in 1913 and 1914 where the joints were originally installed in about 1895, thereby indicating that the majority of the joints will last as long as the rail, the failure being due to the rail itself and not to the joints.

The most prevalent cause of failure in the cast-weld joint is the loosening up of the rail in the joint.

COMPANY 11.—Riveted and thermite-welded joints (Clark joints) have been in use but three years. So far we have had no failures and no defective joints where applied to new rail. Every indication points to a life of this type of joint equal to the life of the rail.

Lorain electrically welded joints have shown but from 1 to 5 per cent, or more failures per annum, depending upon the condition of the rails.

Bolted joints will in no case last as long as the rail.

Our experience with cast-welded joints has been more satisfactory than with bolted joints. The percentage of failures is not as great as in electrically welded joints.

Electrically welded and cast-welded joints have nearly all been applied to partly worn track; therefore our experience is probably not a fair guide to similar joints applied to new track.

In electrically welded joints the failures are due to many causes, principally the breaking of the rail at the ends of the welding bars, splitting of the web above the bars and the depression of the head due to nonsupport.

Cast-welded joint failures are due to depressed or cupped heads and split webs. There are very few cases where joints show any true welding.

COMPANY 16.—In the 100 thermite joints there have been four breaks in four years of service. The rest show serious mechanical wear which will soon require extensive repairs or replacement. The life of other types of joints varies with service and the care taken of the track. Under our average conditions a continuous type of joint should last from 12 to 15 years. We have no definite data in this respect, as this type of joint has not been in use long enough to require replacing.

The thermite-welded joints have failed by breaking due to contraction of rail. They also show very rapid mechanical wear, due to the soft material in the weld. This latter cause of failure has largely been removed by recent improvements.

COMPANY 17.—The most prevalent cause of failure of a mechanical bolted joint in our case has been due to not drawing the rails together as tightly as possible before finally bolting on the joint and the irregularities in the rolling of the rails.

The few welded joints we had have not given satisfaction, to some extent on account of being used on old track. We have never had any on new steel.

COMPANY 18.—In regard to cast-welded joints would say that they have given good service for 15 years and taken as a whole I consider that they have been a success. Of course there have been some failures and in the 15 years a great many mechanical joints have been substituted for the welded joints, but I judge that this has not amounted to more than 10 per cent, and would possibly be as low as 5 per cent of the total number. After 13 to 15 years service these joints are still failing at the rate of probably 1 per cent or 2 per cent per year, and of course the failures in previous years have been less than that amount.

In regard to mechanical joints I believe that a very much larger per cent of these have failed or required repairs. What the percentage is no man can tell. A large percentage of those failures I attribute to the fact that a great many of the mechanical joints were not put on with care that should have been exercised, nor with proper material used in the bolts. Recent experience would indicate that mechanical joints when properly applied could be made to hold with as small percentage of failures as can be obtained with welded joints.

The joints made with the thermite welds have been used only on compromise joints. The percentage of failures of these has been negligible.

No attempt has been made to replace welded joints which have failed. In cases of that kind we have always substituted mechanical joints.

COMPANY 19.—The life of a joint nowadays will in most cases equal that of the rail. And while the joint may "pound" within five or six years, depending on the nature of the traffic, they can be built up and smoothed off with electric welders and grinders so that the joint can be maintained as long as the rail itself.

The most prevalent cause of failure is the giving away of the track foundation owing to water leaks saturating the soil under the track foundation.

COMPANY 22.—Failure on 1600 thermite welds, late type, not over 1 per cent per annum, no exact record, however.

On 800 arc welds no failures to date where joints were properly welded.

COMPANY 27.—The failures of cast-welded joints per year is less than three-fourths of 1 per cent of the total number of joints in use.

The usual cause of failure on cast-welded joints results from either imperfect weld or from excessive pounding at the joint due to imperfect surfacing or wear.

COMPANY 32.—Cast welds: The castings crack, the rails pull out of the castings, or the receiving rail wears out due to the softening of the rail by the welding heat. The latter is the most prevalent cause of failures.

Channel-bar joints and angle-bar joints: Loose bolts are probably the cause of the greatest number of failures in these joints. If these joints are not properly fitted to the rail or bolts are not kept tight, the plate is bent or deformed under the rail head on the receiving side of the joint.

Nichol's composite joint: No failures have occurred since these joints were installed three years ago.

COMPANY 34.—The 8 miles of electrically welded joints were installed in 1906 and are in good condition at present. Only seven joints have broken.

This is on suburban road with expansion joints every 1000 feet.

COMPANY 37.—Have had but three failures on 50 000 Clark joints, standard since 1906.

(*e*) QUESTION 5. COST OF JOINTS.—The following cost data are, in some instances, of little significance, as they are given without information as to weight of rail or as to whether the cost includes the bonding of the mechanical joint or the renewal of pavement. They are tabulated under the various types of joints for which costs were given and include both labor and material.

CAST WELD

Company	Rail	Cost
3	7-inch and 9-inch rail	$5.50
4	6-inch and 7-inch rail	3.75
18		3.50
19	109-pound and 107-pound girder rail	3.14
25	62-pound T rail	4.87
25	70-pound rail	4.87
26	56-pound, 85-pound, and 91-pound rail	8.00

CAST WELD—Continued

Company	Rail	Cost
25	70-pound rail	$5.24
27	91-pound T rail	4.00
29	60-pound and 70-pound rail	5.50
32	9-inch rail	3.00
32	7-inch rail	2.60
32	6-inch rail	2.50
32	95-pound T rail	2.70
	Average cost	4.30

THERMITE WELD

16	9-pound to 125-pound girder rail	$7.00
18		7.50
22	80-pound girder rail	5.00
22	70-pound, 7-inch girder rail	6.00
25	70-pound rail	4.43
29	Old type on 60-pound to 116-pound girder rail	4.00
	Average cost	5.65

ELECTRIC WELD

3	contract price	$5.50
25	60-pound to 106-pound rail do	6.25
29	116-pound girder rail do	7.00
	Average cost	6.25

ARC WELD

22		$6.23
24	Using old angle bars	1.50
25		4.35

CLARK JOINT

37		$4.60–$5.00

NICHOL'S COMPOSITE JOINT

32	9-inch rail	$8.50
32	7-inch rail	7.75
32	100-pound T rail	7.00

CONTINUOUS JOINT

Company	Rail	Cost
3	7-inch	$4.00
3	9-inch	5.00
16	7-inch and 9-inch	6.00
17	Paved streets	4.80
17	Open track	1.65
18	12-hole plate, including bond	6.25
23	7-inch T rail	2.50
24	Including two 4/0 bonds	5.65
26	40-pound, 56-pound, and 60-pound T	1.75
26	70-pound T	2.10
26	72-pound T	3.05
26	80-pound high T	3.80
29	116-pound, 7-inch girder rail	4.75

DUQUESNE JOINT

32	80-pound T rail	$2.10

100% JOINT

30	70-pound T rail	$2.00

ANGLE BARS

3	70-pound rail	$2.10
3	7-inch rail	2.50
3	9-inch rail	3.00
23	4-hole plates on 91-pound, 7-inch girder rail	1.50
26	35-pound T rail	1.00
26	40-pound T rail	1.10
26	56-pound T rail	1.25
26	60-pound T rail	1.50
26	72-pound low T	2.50
26	80-pound low T	2.80
32	9-inch rail	3.00
32	7-inch rail	2.25
32	100-pound T rail	2.20
32	80-pound T rail	1.50
32	60-pound T rail	1.30
32	40-pound T rail	1.00

(*f*) QUESTION 7. TEMPERATURE VARIATION IN WELDED JOINTS.—The tabulated answers to this question as given in the following statement are no doubt largely based upon guesses or estimates. In no case is it stated that they are taken from experimental observations.

COMPANY 3.—All welded joints are in paved streets where the rail and track is gripped and firmly held by the pavement. The temperature of a rail buried in most pavement in the summer time rarely exceeds 60° average temperature in our climate. Also the rail buried as above seldom goes below 30°, no matter how cold the atmospheric temperature is. The maximum temperature variation of a buried rail in our climate is probably not greater than 40°.

COMPANY 4.—Eighty degrees F to 15° F.

COMPANY 10.—Ninety degrees F to 10° F.

COMPANY 11.—Ninety degrees F to 25° F. The rail never gets as cold or as hot as the air temperature.

COMPANY 16.—The maximum change in temperature of atmosphere is about 100°. The welded joints, being embedded in concrete, are subjected to a considerably less range, probably not over 50°.

COMPANY 24.—Air temperature 0° to 100° F; ground temperature 30° to 70° plus or minus.

COMPANY 25.—Sixty degrees F maximum range.

COMPANY 26.—Ninety degrees F to 20° F.

COMPANY 28.—Fifty-four degrees maximum range.

COMPANY 30.—Seventy-five degrees F maximum range.

(*g*) QUESTION 8. EXPANSION JOINTS.—Eight of the 17 companies use no expansion joints whatever. Those that do are quoted below.

COMPANY 17.—Special expansion joints of a modified slotted angle bar type are used on bridges and viaducts and we also use slotted angle bars in open track at intervals.

COMPANY 22.—On all lines we leave a joint about every 500 feet, which joint is connected by the usual angle bars and bolts. Our experience is, however, that these joints do not move any more than the welded ones, the friction of the pavement holding the rail rigid. On one line 7½ blocks long we installed expansion joints with slotted bolt holes. This line is partly planked and partly dirt filled to the top of the rail, and though most of the joints have broken none of the expansion joints have moved.

COMPANY 23.—With welded joints we use continuous plates every 500 feet and at special work.

COMPANY 25.—Approximately every 400 feet continuous bonded joint. We are not welding any open track.

COMPANY 34.—Expansion joints in the electrically welded track are placed 1000 feet apart. In other track none, except on open track, where ⅛ inch to ⅜ inch is allowed, depending on temperature when laid.

COMPANY 37.—Do not use expansion joints on regular work. Only expansion joints we have are on long viaducts, where rail is fastened directly to bridge members.

IV. ANALYSIS OF DATA

1. THE MECHANICAL JOINT

That the problem of rail-bond maintenance is largely that of joint maintenance and becomes serious only where loose rail joints exist is attested by a large majority of the operating companies

enumerated in Section II of this paper as well as by the verbal testimony of the engineers of a number of other companies. It is apparent, therefore, that the first step in an attempt to reduce the present high percentage of bond failures should be toward bettering the condition of the bolted joint.

The principal causes of failure of the ordinary bolted joint have been frequently discussed and are more or less familiar to the majority of electric railway engineers, and will here be reviewed only briefly.

(*a*) DEFECTIVE ROADBED.—This includes poor ballast, poor drainage, water leaks, and decayed ties. While these defects are external to the joint proper, they nevertheless exist and will tend to the ultimate failure of the best of bolted joints.

(*b*) NONUNIFORMITY OF RAIL SECTIONS.—No two rail sections will be found to be absolutely identical. The difference will vary from an inappreciable minimum to the maximum allowed in the specifications adopted by the American Society for Testing Materials. These inequalities are the result of wear of rolls and different degrees of shrinkage with cooling. When two unequal rail sections are joined together by uniform splice bars it is evident, therefore, that the bars do not fit with equal closeness the fishing surfaces of the two rails at the joint. With the passage of the wheel over such a joint one rail will be depressed below the other and pounding of the joint will result, particularly if the receiving rail is the lower of the two. Continual pounding of a joint eventually develops a cup in the receiving rail and rapid depreciation follows if the joint is not given proper attention

(*c*) DEFECTIVE RAIL ENDS.—Rails rolled some years ago by some of the steel companies had a distinct dip of the head at both ends. When joined together a depression or cup was left at each joint which, if allowed to remain, resulted in further wear and early failure of the joint. An order of rails received in Worcester, Mass., at one time was so defective in this respect that both ends of all rails had to be sawed off before they were installed. While this condition has not been met with in recent years it has no doubt been the cause of a number of joint failures in the past.

(*d*) FAILURE TO GRIND JOINTS.—Slight inequalities exist in rail heads as well as in the fishing surfaces, so that on newly bolted

joints a difference in elevation of the abutting rails often exists and unless filed or ground down to a perfect surface alignment will soon develop pounding and cupping. A number of companies now make a practice of running over all newly bolted joints with a track grinder and find that the slight expense is well justified by the increased smoothness and resulting longer life of the joints.

(*e*) Loose Bolts.—This is by far the most universal and prevalent cause of complaint in connection with joint failures and has been the source of constant annoyance and expense to practically every electric railway in the country. Bolts become loose through various causes. They are stretched beyond their elastic limit when being tightened and are thereafter unable to accommodate themselves to expansion and contraction incident to temperature changes and to the vibrations from traffic. As soon as the tension on the bolts is thus relieved the joint begins to work, which allows the plates to wear and further augments the pounding and cupping. It is practically impossible to permanently install joint plates before traffic is put on the track. Slight inequalities in plates and rails permit their intimate contact only at points, and until these high places are worn off or flattened by several days' traffic a proper seating of the plates is difficult. A number of operating companies now follow up all bolted joint installations and take up the slack in the bolts which has developed with a few days' traffic. This practice is obviously commendable and should be rigidly adhered to under all circumstances. The tightening of bolts on all exposed joints once each year or at other regular intervals is practiced by some companies with a corresponding increase in the average life of the joints.

(*f*) Improved Bolts.—Perhaps the most important improvement in the bolted rail joint in recent years and the one which will do more than any other thing to lengthen the life of the joint is the substitution of improved bolts for the more inferior grades. Within the last few years bolts having a high elastic limit as well as a great ultimate strength have been put on the market by several manufacturing companies and are now coming into general use both for special work and straight track.

A large number of companies was consulted regarding the properties and effectiveness of these bolts, and, while a number of

them stated that trial orders had been placed for a limited number or that they were experimenting with them and believed them far superior to the old bolts, practically no one was in a position to give positive testimony based on observations covering any great length of time. One notable exception to this was found with the Harrisburg Railway Co., which was using improved bolts on a steam railroad crossing where endless trouble had been experienced with ordinary bolts, including various patent washers and lock nuts. After the installation of the improved bolts no trouble was experienced and though no lock nuts or other precautions have been employed to keep the nuts tight they have shown no tendency to work loose since their installation.

In answer to question E–3–87, in the June publication of the A. E. R. A. for the year 1915, asking for information as to the economy of using special heat-treated bolts in the joints of railroad crossings and special work the following interesting replies are quoted:

A. E. Harvey, Chief Engineer Metropolitan Street Railway Co., Kansas City, Mo.—After a careful study of this question for several years the writer became convinced that one of the principal factors in the failure of mechanically applied joints was the poor quality of material used in bolts which failed in time, not through the stripping of threads or breaking, but through a gradual stretching and loosening. Over a year ago the use of the high-grade steel bolt with an elastic limit of 75 000 pounds was begun, and they have given excellent satisfaction. The high elastic limit permits of the stretching of the bolt, to some extent, without its receiving a permanent set, thus tending to keep the nut tight. Bolts for this work need not necessarily be material of alloyed steel or heat treated. There are a number of concerns that now manufacture bolts of high-grade steel with an oil finish that answer every purpose in track work and that at a very slight cost above that of the ordinary track bolt. The above applies not only to the use of bolts in special work and railroad crossings but in all track work.

A. V. Brown, Engineer Maintenance of Way Lake Shore Electric Railway Co., Sandusky, Ohio.—Have had excellent success with heat-treated bolts at crossing frogs and are now specifying them on all crossings.

H. A. Clarke, General Manager Ithaca Traction Corporation, Ithaca, N. Y.—I would advise that I have not made use of special heat-treated bolts for such purposes but have used special steel-alloy bolts, having a very high tensile strength, and we find that it is economical. The breaking of such bolts is diminished at least 50 per cent, and in addition the crossings and special work are held more rigidly, decreasing the wear on the joints. We have also found it economical to use special alloy-steel bolts of high tensile strength for ordinary joints. We have found a great many of the ordinary track joints becoming loose, due to the stretch of ordinary bolts. This is almost entirely overcome by the use of special alloy bolts.

J. B. Tinnon, Engineer Maintenance of Way Chicago & Joliet Electric Railway Co., Joliet, Ill.—The first cost of heat-treated bolts is about twice that of ordinary bolts, but the fact that they no not stretch as easily will alone save their extra cost, because they will not require tightening as frequently. Heat-treated bolts are also much tougher than ordinary bolts and are therefore not so easily broken by sudden shocks; in fact, they have to be cut about two-thirds through before they will finally break off. Since the stretching of the bolt is the cause of most loose and broken bolts, the advantage of a tougher bolt that will not readily stretch is very obvious.

George H. Pegram, Chief Engineer Interborough Rapid Transit Co., New York, N. Y.—Our experience does not justify me in specifying special heat-treated bolts. Our specifications, however, require a bolt of high tensile strength with a severe bending test, which requires a high quality of steel.

This testimony in favor of bolts having a high elastic limit as against iron or even carbon-steel bolts is apparently conclusive, and the slight additional expense is completely justified by the decreased maintenance and additional life of the bonds and joints, to say nothing of the improved riding properties of the roadbed.

(*g*) Joint Plates.—The character of joint plates affects the life of rail bonds in so far as they have to do with the general condition of the joint with respect to deflection and vibrations and also as they tend to restrict the natural vibrations and movements of concealed bonds.

(*h*) Room for Concealed Bonds.—A concealed bond, i. e., one installed under the joint plate, is ordinarily subjected to two kinds of vibrations. It is bent or deflected by the deflection of the joint under the car wheel, and it is lengthened and shortened by the diurnal expansion and contraction of the rails on exposed and other joints where such expansion and contraction takes place. Concealed bonds are designed to accommodate themselves to these motions and do so admirably when not restricted in their natural movements by the action of the plates or bolts.

The vibrations and bending of bonds incident to the vertical motion of the joint and rail end is supposed to be taken care of by making the bond long enough to withstand such vibrations, while the longitudinal motion resulting from expansion and contraction is taken up by the crimp which is put in all concealed bonds. The ability of a bond to withstand vibrations depends largely upon its length. This relation has been made the subject of experimental investigation by the American Steel & Wire Co. and other manufacturers of bonds. A vibration testing machine

designed to approximate the motions of a very loose rail joint grips the bond terminals and gives them alternate vertical displacements of any desired amount. With every 125 vertical oscillations the bond is lengthened and shortened once through any required distance. The following figures are given as results of tests on bonds of various length: 7-inch bond began breaking at 41 000 vibrations; 8-inch bond began breaking at 215 000 vibrations; 10-inch bond began breaking at 1 279 000 vibrations; 14-inch bond began breaking at 7 887 000 vibrations.

This test gives no indication of the life of a bond on a good joint but represents extremely poor track conditions. Converting these figures into years of life on a track carrying double-truck cars under a six-minute headway we find that the 10-inch bond will not begin to fail for five years and the 14-inch bond will remain intact for approximately 30 years. That such performances are never realized in practice on bad joints and seldom on perfect ones requires no argument.

Without a doubt the chief difference between the laboratory life test and performance under service conditions lies in the fact that in the latter case the full length of the bond is seldom if ever utilized, but is restricted by the squeezing action of the plates, or the crowding action of the bolts, and in double bonding sometimes by the protruding button of the bond on the opposite side.

The ordinary splice bar, such as is used on steam roads and which was the only type of joint plate available in the early days of electric railways, makes no provision for the accommodation of the concealed types of bonds and no end of difficulty has been experienced by all operating companies on this score, particularly with the smaller rail sections. There is general complaint that the steel companies have been slow in rolling plates specially designed to meet this problem and numerous companies, in their earlier installations, resorting to the only available material, applied concealed bonds under plates which did not permit of their free movement and thereby led to their early failure.

Fig. 13 shows how the bolts and Fig. 14 how the button of the bond on the opposite side might easily prevent any movement of the bond between these points and the bond terminal, particularly under plates which have not been designed to take care of this feature.

FIG. 13.—*Showing interference of bolts with movement of bond*

FIG. 14.—*Showing interference of bond terminal in double bonding*

FIG. 17.—*Clip to prevent separation of ribbons*

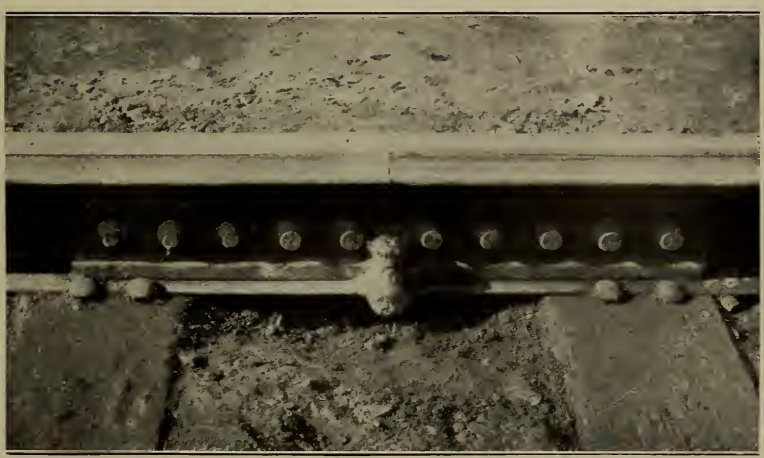

FIG. 22.—*Completed Clark joint*

On badly worn and loose joints of the type shown in Fig. 13 the entire vertical motion of the bond is confined to the short region between the bolts nearest the rail ends and in bonds which are hugged tightly by the plates to a still more restricted length. Such a condition results in the breaking of the strands, not at the bond terminals, as would happen with no restrictions, but at the juncture of the rails or near thereto. Even upon well-maintained joints in which there is practically no vertical motion the continual lengthening and shortening of the bond resulting from expansion and contraction, and which is confined to a comparatively short length, will produce the same effect. Such failures have been more prevalent on open track, where rails experience the full effect of temperature variations, than in city streets. This may be partially the result of better ballast and heavier rails in the latter type of construction, but it is quite reasonable to suppose that the linear expansion and contraction which takes place on the open track is largely responsible for the crystallization and breaking of the strands and ribbons.

(*i*) Examples of Bond Failures.—Companies 2 and 14 specifically state that expansion and contraction in rail joints is responsible for bond failures, and Company 16 says that the failure of concealed bonds is confined to those joints in which expansion and contraction of the rails takes place in the joint. The Boston & Worcester Street Railway Co. presents a striking example of this type of bond failure on their suburban line between Boston and Worcester. It is reported that only a small per cent of the original 12-inch concealed-wire bonds are now in service, a large majority of them having failed by the wires breaking in the middle near the juncture of the two rails.

Engineers of the American Railways Co., which operates a number of properties, state that they have had difficulty in obtaining room for concealed bonds on rails of 60 pounds per yard and smaller. On large rails they report ample room and state that they will permit of very loose joints without breaking bonds, while the slightest motion in the joints of the smaller rail sections will quickly result in broken strands or ribbons.

Some of the bond manufacturers have attempted to meet this problem by providing the operating companies with stranded

bonds having a triangular section. A sectional view of such a bond installed is shown in Fig. 15. While this may be an improvement over a bond having a circular section, its very necessity is an acknowledgment of a condition which requires a more drastic remedy.

(*j*) SPECIAL PLATES.—Some of the larger and more progressive companies have called on the steel manufacturers to roll special plates for them which have been designed to give room for concealed bonds. This has been done in some cases and in a few instances such plates have become standard with the manufacturers. This is particularly true with respect to the manufacturers of some of the patent joint plates, such as the continuous joint and the Bonzano joint. Fig, 16 shows a sectional view of continuous joint plates applied to a 40-pound rail. It is seen that ample room is provided for concealed bonds. The joint plates recently adopted as standard by the Amerian Electric Railway Association were designed to give ample clearance for bonds and are now being rolled. These standards, however, were adopted for only the 7-inch and 9-inch rails, on which the problem of bonding was not so difficult as on the smaller sections.

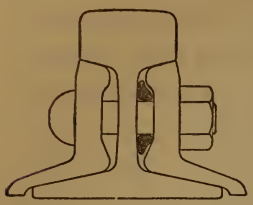

FIG. 15.—*Standard joint plates, showing inadequate space for bond*

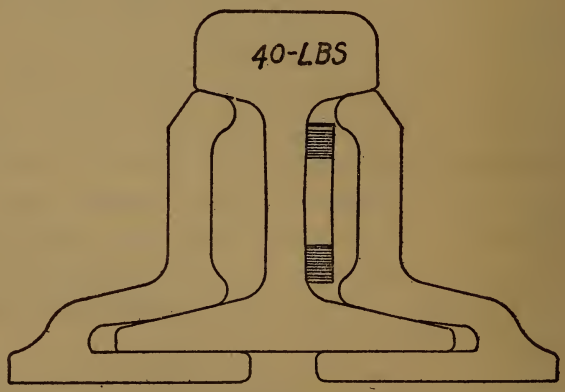

FIG. 16.—*Special plates, showing ample provision for bond*

(*k*) IMPROVED JOINT PLATES.—Not only do some of the improved joint plates materially increase the life of concealed bonds by giving ample clearance for them, but their ability to better support and maintain the joint than the old types of plates is sufficient justification for their use. Among the improved bolted joints the continuous joint seems to be the most popular with the operating companies. Figures submitted in Table 6 show that 19 companies reported the use of this type of joint, whereas the largest number using any other

type of improved plates is 3. The total number of continuous joints reported is 68 669, which is more than twice the number of all other types of improved joints reported.

This type of joint plate when properly installed with bolts having a high elastic limit grips the rail so firmly that expansion and contraction within the joint is largely eliminated, particularly on city tracks. We quote Company 3 with reference to this point:

> We think if the bolts in continuous joints are drawn tight there is very seldom any slipping of the joint, due to expansion or contraction, as this joint grips the rail very firmly, so that a well-bolted continuous joint gives nearly the same effect as welding.

The type of bolted joint referred to under "Mechanical joints" in Section II of this paper, wherein a shop fit is obtained by reaming holes and using machine bolts and in which no expansion and contraction is allowed, has, to our knowledge, not been used on open track, although welded joints have been used in a number of installations for this purpose, expansion and contraction being taken care of by expansion joints at regular intervals of about 500 to 1000 feet. If such improved bolted joints were used on open track in connection with expansion joints, a great reduction in the maintenance cost of both bond and joint would be affected, to say nothing of the economy of operation and improved operating conditions generally. The ultimate economy of such construction would have to be carefully considered for any given project, but that it would be fully justified on heavy traction lines is firmly believed. If installed according to the best modern practice, bond failures would be reduced to a minimum, being relieved of the continued lengthening and shortening so prevalent in the ordinary joint. Maintenance would consist of occasionally going over the joints and tightening the bolts. If in time the rail ends began to cup, they could be inexpensively built up by applying new metal with the arc welder or acetylene flame and then ground to a true surface alignment. Such joints with the comparatively slight maintenance here mentioned would undoubtedly have a useful life equal to that of the rail and at the same time provide a continuous and permanent return circuit for the electric current. We believe the type of construction here described to be not only practicable but of ultimate economy, and urge its adoption by the operating companies at least on an experimental basis.

14985°—16——5

2. TYPES OF BONDS AND FEATURES OF INSTALLATION

(*a*) COMPARISON OF COMPRESSED AND PIN TERMINAL BONDS.—Stud-terminal bonds according to our definition on page 12 include both compressed-terminal and pin-terminal bonds, and each of these types comprise ribbon and wire bonds for both concealed and exposed application.

The tabulation on page 29 shows that 929 600 compressed-terminal bonds were reported as against 362 800 of the pin-terminal type. These figures, together with a majority of testimony as to preference, indicate that the compressed terminal is easily the favorite among a majority of the operating companies. On the other hand, however, must be considered the fact that the pin-terminal bond has been adopted as standard and is being employed with phenomenal success by a number of the largest operating companies, including the New York Central & Hudson River Railroad Co. and the Pennsylvania Railroad. While it is not possible to say in general that one of these types is better or worse than the other it is hoped that a careful analysis of all information available will aid in reconciling the differences in opinions regarding these two types, and establish the fact that each type has characteristics and properties which makes it peculiarly adaptable for certain classes of work or under certain special conditions.

One of the arguments put forward in favor of the compressed-terminal bond is as follows: The contact resistance between copper and steel decreases as the pressure increases up to about 30 000 to 40 000 pounds per square inch. As copper reaches its elastic limit and begins to flow at about 20 000 pounds per square inch, the minimum contact resistance is not reached with the pin-terminal bond since the copper is not confined during the driving of the pin, but is free to flow out around the pin, forming a button on the opposite side of the rail as is illustrated in Fig. 3. With the compressed-terminal bond, it is argued, the copper is confined between the terminals of the compressor, and not being able to escape is subjected to a pressure limited only by the design of the compressor or the diligence of the workmen.

This argument, which at first may appear to be tenable, is undoubtedly fallacious. It is true that very soft and thoroughly

annealed copper has an elastic limit of about 20 000 pounds per square inch, but upon undergoing a very small amount of manipulation it rises rapidly to from two to three times this value. As the action of the compressor or even the driving of the expanding mandrel produces a distortion in the copper more than sufficient to bring about this change in the elastic limit it is obvious that the pressure required for minimum contact resistance is reached in both the compressed and pin terminal type of bonds.

If there is any difference in the contact resistance of these two types it appears to be so slight as to have practically no effect upon the total resistance of a bonded rail joint. The average of 32 tests on each type conducted by the Chicago Board of Supervising Engineers in 1911 shows the pin-terminal bond to have a conductivity of 96.65 per cent of that of the hydraulic-compressed bond and 98 per cent of that of the hand-compressed bond. As the double contact resistance of a 4/0, 10-inch, copper bond is only about 20 or 25 per cent of the total resistance of the bonded joint the slight difference in the contact resistance of the two types would affect the total resistance of the joint in the order of a fraction of 1 per cent, which is so small as to be entirely negligible for practical purposes.

The contact resistance of a stud-terminal bond when newly and properly installed is often quite a different thing from the resistance of the average bond after being subjected to several months or years of service. That the two may be quite different is evidenced by the greater part of the testimony recorded in answer to question 18, although several companies believe that bonds show little if any increase in resistance if the joints are properly maintained. The increase in the resistance of a joint in some instances may be solely the result of the loosening of the joint plates. Tests recently conducted by the Bureau of Standards, the results of which are given on page 119 of this paper, show that newly bonded and bolted joints have a much lower resistance with the plates on than with the plates removed, indicating that tightly bolted plates add very materially to the conductance of a rail joint. Also recent tests of joint resistances on unbonded tracks which have been in service for a number of years show

that only about 5 per cent of unbonded joints have a resistance less than 1000 feet of rail.

While these tests might in some cases account for the apparent increase in resistance of bonded joints, it is undoubtedly true that a large number of the mechanically applied bonds slowly increase in resistance and may or may not reach a stage, within the life of the joint, where corrosion becomes so serious as to require the replacement of the bond.

While contact deterioration has been attributed to the difference in the coefficients of expansion of copper and steel and to other uncontrollable causes, it is undoubtedly true that by far the most prevalent cause of such deterioration is natural and electrolytic corrosion resulting from the entrance of moisture between the two metals. Considerable evidence is at hand to show that, as a rule, on compressed-terminal bonds moisture finds admission to the bond terminal between the head of the bond and the steel on the bond side of the rail. Engineers of the American Railways Co. state that they have removed hundreds of compressed-terminal bonds after being in service for a time and that on nearly every one the corrosion had started on the shoulder of the terminal on the bond side of the rail.

Experiments conducted by bond manufacturers have demonstrated that, under the action of a compressor, a bond terminal will begin to expand at the end opposite the head of the bond, and will gradually fill the hole toward the head as the pressure is increased. It is evident, therefore, that such failures as those reported by the American Railways Co. are the result of incomplete compression and emphasize the necessity of careful attention to this feature.

The life of poorly compressed bonds is possibly lengthened by grinding or otherwise cleaning, at the time of installation, the web of the rail with which the bond terminal comes in contact. Company 10 reports that they have greatly increased the life of their compressed-terminal bonds by this operation and attribute it to the good contact between the head of the bond and the web of the rail, which they believe delays the entrance of the moisture to the terminal proper.

A few complaints have been registered against the pin-terminal bond on account of the steel pin being subject to corrosion when allowed to come in contact with the earth. It is claimed that corrosion of the steel pin takes place and rapidly rusts it out, thereby relieving the compression on the copper terminal.

The great advantages of the pin-terminal bond as claimed by the friends of that type are, first, that it can be installed with uniform and consistent results by ordinary labor, while the compressed-terminal type requires careful and expert labor for satisfactory results; and, second, it can be installed without interruption to traffic or the danger of a derailment, which is possible when using a compressor across the rail.

Regarding the first point there appears to be a division of opinion, some claiming that the compressed-terminal type is more nearly "fool proof" than the pin-terminal bond. It is claimed by advocates of the compressed type that the big New York companies, who are having such phenomenal success with the pin-terminal bond, were forced to the adoption of that type by company rules which forbid the use of a compressor or any other tool which might cause a derailment; and the rigid specifications and extreme refinements which they have adopted in connection with the purchase and application of their bonds inclines one to the conclusion that this, rather than the first-mentioned reason, was the determining factor in making their selection.

It is significant that the principal advocates of the pin-terminal bond are to be found among the larger operating companies. The Philadelphia Rapid Transit Co. and the Bay State Street Railway Co., both operating extensive systems, may be added to the list of New York companies already mentioned. The observations of J. B. Taylor, engineer of way for the Philadelphia Rapid Transit Co., may throw some light on this point.

Mr. Taylor states that in a system of the size of that in Philadelphia a number of repair jobs are usually in progress at the same time and it would not be practicable to have expert bonding men at every job at the proper time. When the rails are ready the bonds must be applied, and as pin-terminal bonds can be installed quickly and with a fair degree of uniformity by an ordinary trackman, they are found to be better suited for this

class of work than the compressed-terminal bond, which should not be installed by any but an experienced and careful workman.

The Bay State Street Railway Co. has a thousand miles of track in and around Boston. They adopted pin-terminal bonds five years ago because of the ease and uniformity with which they can be applied and for their "fool-proof" qualities. All bonds are purchased under rigid specifications based on their own drawings. Many of them, consequently, are not standard products of the manufacturers. Types and sizes are selected by laying out on the drawing board the rail and joint-plate sections and then prescribing a bond that has plenty of clearance.

The extreme care with which the New York Central & Hudson River Railroad Co. installs their pin-terminal bonds has already been referred to. The reported price of 35 cents per bond for labor on installation is an indication of the grade of labor and the care employed. It is said that bonds are installed in only freshly drilled or reamed holes, and that the bond terminals are cleaned and polished before they are expanded. A driving fit must be secured and if a hole is found to be larger than the bond terminal it is reamed out and a larger terminal inserted, or if the difference is small a larger expanding pin is used. Finally, the expanding mandrel and pin must be of the correct diameter to insure proper expansion. Too large a pin will tear the metal, while too small a pin will not insure complete expansion. Three companies are manufacturing the standard 16-inch 500 000 cir. mil stranded bond employed by this road, which is a special product, as no other operating companies use the same bond.

That the careful and expensive methods of bonding employed by this company are fully justified is indicated by the extremely small percentage of failures recorded on page 36 of this paper. The following set of specifications which are required by the Bay State Street Railway Co. are similar to those required by other large companies employing pin-terminal bonds and may prove of interest to bond purchasers:

RAIL BOND SPECIFICATIONS.

Definition of terms.—The word "company" where occurring in this specification shall mean the purchaser of the material hereinafter referred to, or its duly authorized representative.

The word "contractor" where occurring in this specification shall mean the party accepting the order to furnish the material hereinafter referred to, or its duly authorized representative.

General description.—The materials required under this specification are 4/0 A. W. gauge capacity bonds, for bonding around track joints.

The completed bonds and the materials of which they are made shall conform in design and dimensions to the company's standard drawings, hereby made a part of this specification and to the following requirements and tests:

Conductor.—All bonds shall consist of the required number of annealed copper wires or ribbons, free from splints, flaws, or other defects, and having an aggregate cross sectional area, when measured at right angles to the axes of the individual wires, at least equal to that of 4/0 American wire gauge.

Each of the individual wires or ribbons shall have a conductivity of not less than 98½ per cent of standard annealed copper at 20° C.

Where stranded bonds are required the wires shall be concentrically stranded together in spiral layers having at least one complete turn in each 5 inches of conductor.

The copper wires shall not vary more than 1 per cent from the nominal diameter.

The copper ribbons shall not vary from the nominal widths and thickness more than the amount shown in the following table:

Thickness, in inches	Variation, in inches	Width, in inches	Variation, in inches
0. 010–0. 050	0. 001	0. 10–0. 250	0. 003

Terminals.—Where copper terminals are required they shall be in effect a unit with the conductor. This may be accomplished by upsetting the head from a portion of the conductor or by welding drop-forged terminals on the conductor, in which case the union between terminals and the cable shall be a clean weld, free from oxide.

The terminals shall be of uniform size and shape, free from cracks, burrs, fins, slivers, and hard spots, and any machining on terminals shall be followed by careful annealing.

The surface of the terminals as called for on the drawing shall be milled smooth or otherwise finished, the resulting surface to be strictly equivalent to that obtained by careful milling.

Where steel terminals are required they shall be made of steel of good quality, soft, and carefully shaped to the dimensions specified, and shall be thoroughly tinned inside and out before soldering to the conductor.

The soldered joints between the terminals and cable shall be carefully made with half-and-half solder and shall be free from imperfections of adhesion, excess of solder, or any other defects.

Tests—Union between conductor and terminals.—All bonds with copper terminals may be tested as follows to determine the character of the union between the head and conductor:

The stud of the bond shall be sawed lengthwise into four equal segments, allowing the saw to cut to but not into the conductor:

These segments shall then be bent back, tending to separate the welded parts. If a clean, bright fracture is exhibited, with a surface entirely free from dark oxide, the weld shall be considered satisfactory. It is not essential that the lines of the individual wires or ribbons be entirely obliterated.

Flexibility.—The test for flexibility hereinafter described is not made a condition of acceptance, but may be made at the option of the company and accorded due weight in the determination of the relative excellence of the bonds submitted. This test shall be made by holding rigidly one terminal of a bond while the other end is given a longitudinal movement of three-sixteenths of an inch, and a transverse movement of three-sixteenths of an inch, and continuing the movement until the first ribbon or wire breaks.

Inspection.—Samples shall be selected at random from each type and kind of bond received for inspection and determination if they comply with the specification; the samples shall consist of two bonds from each 100 and at least two bonds if there are less than 100 bonds.

Rejection.—If 10 per cent of the selected samples fails to comply with the requirements of the specification all bonds represented by these samples may be rejected and returned at the expense of the contractor.

Method of shipment.—All bonds shall be so packed for shipment that they will be suitably protected from injury, each package being plainly marked with the number, type, and length of bonds, and the number of the company's order upon which shipment was made.

The argument that it is easier to obtain uniform results with the pin-terminal than with the compressed-terminal bond is largely based on the assumption that it is easier to drive a pin into a bond terminal than to properly adjust and manipulate a compressor. This is no doubt true, but it is also a fact that workmen frequently drive the pins in crooked and thereby fail to get a uniform expansion.

In the installation of compressed-terminal bonds not only must the compressor be properly adjusted so as to get an even bearing on the bond terminal but the maximum compression must be obtained in order to secure the best results. It is also important to keep the point of the compressor in good condition, and the axis of the screw should be at right angles to the opposite face of the compressor. The difficulty of knowing when complete compression has been obtained has led some of the operating companies to the practice of testing each bond at the time of installation. If it does not come up to the proper standard the compressor is applied again or a new bond installed.

One of the manufacturing companies is attempting to provide for this insurance automatically by building a compressor which will shear out a button of sheet metal when the proper pressure has been reached. Workmen will then be required to turn in a button for each terminal compressed at the close of each day.

Granting that attention to these details is obtained only by conscientious and experienced workmen, it is also true that a greater variation in the size of holes is permissible with the compressed-terminal than with the pin-terminal bond. The great care exercised in getting holes of exactly the right size and the rigid specifications regarding the diameter of pin-terminal bond studs is necessary on account of the small amount of expansion that can be obtained in this type of bond. On the other hand, although not good practice, pressure can be applied with a screw or hydraulic compressor until a comparatively loose bond terminal has been made to fill the hole.

Summing up the arguments we are inclined to believe that honors are about even respecting the two types, and we are led to the following conclusions:

Excellent results are obtained with the compressed-terminal bonds when they are carefully installed by experienced men. Inexperienced, untrustworthy, or careless workmen should not be employed for their installation. The compressor should be kept in good condition in order that complete and even compression may be obtained. The testing of bonds immediately after installation is also a good practice. Failure to comply with these requirements is likely to result in poor contacts, followed by corrosion and rapid deterioration.

Results equally as good as those obtained under the best conditions with the compressed-terminal bond may be secured with the pin-terminal type when careful attention is given to the details of installation, particularly to obtaining a driving fit for the bond terminal before driving the pin. This condition can be controlled within narrow limits by specifying only machined-terminal bonds and giving close attention to the grinding of drills. The reaming of all holes with a straight reamer is a good practice and will add greatly to the uniformity of results. Moderate and fairly uniform results can be obtained with the pin-terminal bonds when installed by ordinary inexperienced laborers if they are provided with uniform bonds and pins as well as drills which have been ground at the shop. This is owing to the fact that under these conditions the personal element has been largely eliminated, and so long as

the pin is driven home there is a fair assurance that a good and permanent contact exists.

Compressed-terminal bonds are often excluded from use on rapid-transit lines where the compressor over the rail would offer a hazard to the safe passage of trains, also from special work where the sharp angles of the frogs sometimes prevent its use.

Pin-terminal bonds are excluded from use on elevated roads and other tracks where wooden or steel guard rails prevent the use of a hammer in driving the pins. The steel pins in pin-terminal bonds are subject to corrosion and should be used with caution where they are likely to be subjected to excessive moisture.

The following code of instructions for the installation of pin-terminal bonds is given by Howard H. George in the Electric Railway Journal of September 19, 1914. It represents the best modern practice and has been incorporated in Prof. Richey's Electric Railway Handbook. All of the 13 rules, with the exception of 10 and 11, apply equally well to compressed-terminal bonds.

CODE OF INSTRUCTIONS FOR INSTALLING RAIL BONDS

1. Every roadmaster and foreman should see that one or more men in each gang are taught the proper way of installing bonds, and should be sure that any bonding done thereafter is performed by these men.

2. When renewing rail or joint plates on single track in operation, care should be taken not to open or disconnect both rails at the same time, as this would open the return circuit by which the current returns from the cars to the power house. When it is absolutely necessary to open both rails, a long copper jumper should be installed to connect the open ends so that the path of the return circuit shall not be interrupted. This applies more particularly to road ends and interurban lines.

3. Whenever any track is opened up and any ground wires for electric lights, lightning arresters, or other electrical apparatus which should be connected to the rail are found disconnected, they should be reported at once to the bond inspector, or distribution department, so that they may be repaired before the track is closed up. This is very important and should receive careful attention.

4. No bond holes should be drilled until just before the bonds are ready to be put in. There are, of course, times when it is desirous to have the holes drilled before the rail is placed on the ties. When this occurs, it is necessary to place a tight-fitting plug in the hole as soon as it is drilled to avoid any possible introduction of moisture. To drill a hole a day or two before and not protect it from moisture means a film of rust in the hole, which will greatly increase the resistance of the joint.

5. Old bonds should never be used again, because they become battered up in driving them out. Then, when they are put in again they will not make good contact with the rail, which means a poor bond. Where a bond is removed from the rail it is not advisable to use the same hole in putting in a new bond, unless some pre-

cautionary methods are used. The proper way is to drill a new hole, but as this is not allowable in some types of rails, ream out the old hole and use a bond with a special large size terminal.

6. Great care should be taken with the drills used in making bond holes. If an improperly ground drill is used the hole will be irregular and oval shaped, thus giving a poor contact between the terminal and the rail. All dull and broken drills should be carefully boxed, labeled, and sent to the shop to be reground, where the company has installed a special machine for the purpose to do the work perfectly and at much less expense than could possibly be done by hand.

7. In drilling bond holes never use oil to lubricate the drills. It is better not to use anything, but where it is absolutely necessary to use a lubricant, nothing more than a soda solution should be employed.

8. Holes, after being drilled, should be carefully cleaned of any chips and wiped dry of any solution that may have been used to lubricate the drills. The holes must have a smooth and dry surface, so that the bond terminal will make a good contact all around.

9. With a proper size hole, the bond terminal will make a very snug fit, not small enough to have to be driven with a heavy maul nor large enough to be put in easily with the hands. It should require a couple of taps with a hammer weighing about 3 pounds. With a heavy hammer or spike maul the head of the bond terminal is very likely to be battered and the taper punch struck on the slant, causing it to split and bend the terminal.

10. After the bond terminals are in position, always drive the long steel taper punch entirely through the terminal, taking care to strike the punch squarely on the head. The small end of this punch should be dipped in some kind of heavy grease, such as track grease, just before it is driven through each terminal. The grease will lubricate the sides of the punch, thereby expanding the terminals and not drawing the copper with the punch.

11. Drive into each of the expanded terminals one of the short drift pins, thus expanding the copper a little more. This pin should be driven in until it is just flush with the head of the bond terminal.

12. The bond should then be shaped by straightening out the bond conductors, and forming them so that they will not be cut by either the track bolts or the splice bars. If it is a 36-inch bond, it should be so shaped that it will in no way interfere with the removal of the splice bars.

13. The bond, and particularly the bond terminals on both sides of the rail, are to be painted with some good weatherproof paint, care being taken to see that the paint fills the space back of the terminal heads.

(*b*) STRANDED V. RIBBON BONDS.—Referring to the tabulation under question 3, on page 29, we find that a total of 579 200 stranded concealed bonds were reported, as against 214 200 ribbon bonds. Considering that the section of the ribbon bonds is much better proportioned for the space usually provided for concealed bonds, this apparent preference for the stranded type may seem surprising. Manufacturers who have conducted laboratory life tests on the two types differ as to their relative abilities to with-

stand vibrations. The American Steel & Wire Co. states in their general catalogue that the stranded bond will remain intact longer than the ribbon bond, while the Electric Railway Improvement Co. affirms that many vibration tests on short head bonds have demonstrated that the ribbon bond will outlast the wire type. This seems to be another case where theories and laboratory experiments offer little evidence as to what will happen under the peculiar exigencies of service. The fact is that the majority, though not all, of the operating companies are using and prefer the stranded bond for concealed work and say that it is giving better satisfaction than the ribbon type and is not so sensitive to vibrations and the corrosive action of the joint plates.

The secret of the matter no doubt lies in the fact that the conductors of the ribbon bond, not being twisted or wound together, are easily separated and isolated. The space provided for concealed bonds is wedge shaped, as seen in Fig. 15, and the movement of the plates tend to work the ribbons and strands upward under the fishing surface of the rail head. This is a common complaint, and has been mentioned by a number of engineers. The wires of the stranded bond, being twisted together, are not so likely to become separated and broken by this action.

The effect of loose joints on head bonds installed in macadam or earth streets is similar to that on concealed ribbon bonds described above. Dirt works in between the ribbons, which are gradually separated and brought to the surface by the continual motion of the joint. This trouble has been recognized, and is now being largely overcome by the application of a clip around the body of the bond, which prevents the separation of the strands. This clip is illustrated in Fig. 17.

(*c*) Use of Solder and Alloys with Mechanically Applied Bonds.—The large number of bond failures in past years resulting from corrosion of mechanically applied terminals have led a number of companies to adopt the use of solder or a plastic mercury alloy as a third or intermediate metal between the copper and steel. In some cases compressed-terminal and twin-terminal bonds have been installed with solder, in other cases the terminals have been tinned either at the factory or on the ground before installation, while in still other installations both the steel of the

rail and the bond terminal have been amalgamated. While these various practices have found rather wide application and have many adherents, the manufacturers of bonds are a unit in their belief that the copper to steel contact can not be improved upon. They argue that the introduction of a third metal, having a specifically high resistance, between the copper and steel will not only add to the contact resistance but might also be the source of a chemical action which will hasten rather than delay corrosion. To the argument that a third and soft metal is needed to take up the difference in expansion between copper and steel, they reply that the process of expanding or compressing a copper terminal so hardens it as to give it sufficient elasticity to take up this slight difference in expansion itself. In the absence of experimental data to substantiate these theories we are again forced to base our conclusions upon the best modern practice resulting from years of experience and upon the opinions of prominent engineers. We will consider the practices of soldering, tinning, and amalgamating in the order in which they are named.

The several methods of soldering compressed-terminal bonds which have been used are well described in the following extract from a letter received from the Ohio Brass Co., which developed the thermobonding process, in answer to an inquiry requesting information on the subject:

> The compressed-terminal type of rail bonds has had the most general use in the past, due principally to the fact that it can be installed in a satisfactory manner with the comparatively low grade of labor that must be relied upon for work of this kind. One of the chief objections to the compressed-terminal type of rail bond has been the rather small contact area between the terminal of the bond and the rail. In case the bond is not properly compressed, the contact surface would corrode, further reducing the efficiency of the bond. In order to overcome this difficulty many railroads make a practice of soldering the head of the bond to the rail after it has been compressed. With this method it is customary to tin the bond terminals before they are compressed and after the compression to heat them with an ordinary blow torch, applying solder, so as to form a perfect contact between the head of the bonds and the rail, thus supplementing the contact secured by the compression and excluding the moisture from the plug portion of the bonds, at the same time giving an electrical contact which is not liable to deteriorate. The soldering process, however, adds considerable to the expense of the installation.
>
> The O–B thermobonding process was developed with a view of securing the advantageous results of soldering compressed-terminal bonds, at the same time furnishing a simple and cheap method of making this application. The charge of thermite is set off on the opposite side of the rail from the bond head and generates sufficient heat so

that the bond head can be soldered to the web of the rail. Many of the largest roads in the country using compressed-terminal bonds with solder changed over to the thermo process as soon as it was put on the market, and a great many bonds have been installed in that manner. However, it is an added refinement which is not considered essential, and as it adds considerable to the expense of the installation it has not had a universal use. The process requires some care in the installation, and for this reason, where a low grade of labor is used, further difficulties are encountered.

Where a railway wishes to secure a very high grade of bonding and is willing to take the pains to use the proper care in installing the bonds by the thermo process, it is a very excellent method and is quite successful.

The thermobonding process here described has fallen into disrepute, and disuse so that at the present time it is employed very little, if at all. This has been the result, not only of the causes mentioned in the above quotation, but because of the injury done to the bond terminal and the web of the rail by the excessive heat generated by the thermite. We quote Company 16, on whose tracks a few bonds were soldered for demonstration purposes:

After three years the bonds were removed for inspection, but we are sorry to say that they were in bad condition. The terminals were black and not soldered to the rail at all in the hole, and the excessive heat from the thermite had burnt the rail, which made it brittle and caused the steel to rust and depreciate.

Conditions similar to these were also reported by A. P. Way, electrical engineer for the American Railways Co. Company 15 says regarding the thermobonding process:

About four years ago a thermosoldering process developed by the Ohio Brass Co. was made a part of the standard process of installing a bond. It is supposed to make a complete union between the copper bond and the rail. In most cases it appears to do so, but there have been cases where such bonds were removed several months after installation and the contact between bond and rail has been black instead of bright, thus showing poor contact. This may have been due to poor workmanship in the installation, particularly since bonds installed by this process test good after installation.

A test made by the Chattanooga Railway & Light Co. in November, 1910, shows the resistance of the thermo process bond contact to be approximately one-half the resistance of the compressed type without soldering.

In addition to Companies 14 and 15, which have employed the thermobonding process, may be mentioned Companies 7, 20, and 26, which solder their stud and twin terminal bonds by the aid of a blow torch.

The following letter from Company 20, describing the method as practiced in Tacoma, Wash., will be found of interest:

We are sending you, parcel post, one of our standard 250 M c. m. twin-terminal bonds. The American Steel & Wire Co. have made a special die for the bonds they

furnish us. You will notice that the face of the terminal which comes in contact with the ball of the rail is a flat smooth surface. In applying these we are very careful to see that the ball of the rail is chipped smooth and deep enough so that all rust spots are cut out. Although the terminals are tinned, we redip them immediately before they are applied. We also are careful to see that the holes in the ball of the rail and the chipped surface is perfectly clean and well tinned. The bond is driven with the rail hot and the solder fluid. After the bond is in place, solder is applied to the upper edge of the bond with an iron which makes a reinforcing fillet.

Before adopting this type of bond as a standard, we applied a number of them without solder. Resistance measurements were taken immediately after the bond was applied and at intervals thereafter. We noticed in a number of cases that the resistance of the bonds increased, in some cases slightly and in some cases materially. Since we have been using solder in the application of this bond, we have made a large number of resistance measurements and have not noticed any change in the resistance of the bond.

The bond here described is similar to the Form C twin-terminal bond, but having a broader face and a square shoulder to hold the fillet of solder.

There seems to be a fairly general agreement that solder improves the contact of mechanically applied bonds, but that when applied by the thermo process the chance of burning both the bond terminal and the rail are so great as to offset the benefits that might accrue therefrom. In view of the excellent results which are being obtained with the compressed-terminal bond under the present improved methods of manufacture and installation, the additional expense of soldering this type appears to be hardly justifiable. The soldering process requires skilled labor, additional time, and extra material. If half this time and expense be devoted to careful and improved methods of drilling holes and compressing the bond terminals, equally good results could be obtained. The use of solder in connection with twin-terminal bonds will be further discussed when considering that type.

The process of tinning stud-terminal bonds before installing them has been employed by a number of companies, and apparently with general success. One of the strongest advocates of this practice is found in E. Heyden, superintendent of overhead construction for the Indianapolis Traction & Terminal Co., who is very positive in his belief regarding its value. Mr. Heyden states that he has used tinned-terminal bonds for years, and that in removing bonds from old rails he has invariably observed that corrosion has been much worse on bonds which had not been

dipped. He goes further and says that with a bond tester he is able to distinguish between dipped and undipped bonds when testing the resistance of rail joints.

Tinned bonds are also being used by the Empire United Railways, of Syracuse, where it is stated they show less corrosion than undipped bonds.

The process of amalgamating bond terminals before compressing them is now finding favor with a number of operating companies, among which is Company 25, from whose report the following quotation is taken:

> After using many types of bonds and rail joints, the writer has standardized on the use of compression bonds in connection with which is used the so-called H. P. Brown pastic and solid alloys. These alloys have proved very valuable, in that they take care of any grooves which may be cut in the bond hole when drilling the rail for a bond, and also, being live materials, take care of the difference in coefficients of expansion as between copper and steel at the connection of the bond to the rail. These alloys also form a protective coating over the copper and steel, preventing corrosion near the point of contact.

These alloys have also been used by the American Railways Co., which believes them to be valuable in excluding moisture from the bond terminal.

These alloys are useful only where they are confined, as they soon corrode and lose their effectiveness when exposed to the atmosphere. In the New York power stations, where they were used on copper switches to reduce the contact resistance, they were effective for about three months, after which time the switches showed a higher resistance than before the application of the alloys.

Although the practice of tinning and amalgamating stud-terminal bonds has not been very extensively employed and comparatively little information regarding it is available, it appears that in some installations they have proved very valuable. Both processes are quite inexpensive, and on installations where corrosion of terminals has been a chronic trouble they can, no doubt, be used to advantage. The utility of many materials and practices of this nature depends largely upon the personal element of the workmen involved. One man may learn how to apply compressed terminal bonds and obtain good and uniform results by his individual methods. The same man may utterly fail to get results

with pin-terminal bonds or with soldered or amalgamated compressed-terminal bonds. Splendid results obtained with the use of any type of bond or material are usually the result of the individual efforts of some person who has mastered that particular problem.

(*d*) MECHANICALLY APPLIED HEAD BONDS.—The twin-terminal bond and tubular-terminal, or O–B, type J bond, shown in Figs. 7 and 8, are included under this heading and are so similar in construction and with reference to their features of installation that they may well be considered together.

These types were developed as the result of a demand for a bond that could be installed without removing the joint plates and without undue interruption to traffic. Experience had demonstrated that long bonds which spanned the joint plates were subject to theft, and the types here mentioned were made as short as possible in order to reduce this loss as well as for the sake of economy. The short length has naturally resulted in considerable breakage from vibration, particularly on loose joints, and this is perhaps the most prevalent cause of failure.

While these types are best adapted to open track where they are not subjected to vehicle traffic they have been used to some extent in earth and macadam streets. The cost of renewing a concealed bond in city streets is shown by figures in Section III to range from $1 to $3, depending upon the nature of the pavement. It is argued that the cost of installing a short head bond is so small in comparison to this that a company is justified in its use, although the depreciation in city streets may be high.

Very little testimony has been secured regarding the use of the tubular-terminal bond, as this type has been on the market but a short time. The extent to which it is being adopted on new roads, however, is not only evidence of the general demand for a short head bond but an indication of faith in this particular type. The following information is pertinent regarding its use.

In answer to an inquiry on the subject the Northern Ohio Traction & Light Co. says:

> Replying to your letter of the 2d instant, I wish to advise you that the O–B type J rail bond which we have used has given us very satisfactory service.

The Detroit Railway has the following comment to make:

> Replying to yours of the 2d instant, relative to our experience with the O–B type J rail bonds, I beg to state that we have used a great many of these bonds on suburban work and they seem to be working out very well. I do not recommend them for city street work or for places where vehicles can in any way strike them, as they, like all other bonds of this character, are liable to shear off from the rail.

George F. Silvia, electrical superintendent for the Albany Southern Railroad, states that a systematic rebonding of all the tracks on that road will soon be commenced and that the O–B type J bond will be used exclusively. He believes that where these bonds fail others should be installed by drilling new holes in the head of the rails, as it would not be practicable to attempt to drill out the old terminals.

Recent technical press notices state that on the new Grand Rapids-Kalamazoo line, 50 miles in length, and in the construction of the Fort Wayne & Northwestern Railway the O–B type J bonds are being used.

The testimony relative to twin-terminal bonds is more abundant. Company 11 employs 60 000 and Company 42, 33 000 of the total 113 700 bonds of this type reported. On both roads its use is confined to open track. As these companies are among the largest users of twin-terminal bonds in the country their experience should be significant. Company 11 says in answer to question 6:

> Twin terminal and compressed terminal bonds usually last as long as the track; the percentage of failure is very small.

Company 42 reports that in the seven years of operation 7357 bonds on an original installation of 33 000 have been replaced. Of these 800 had been stolen. This is equivalent to an annual failure of approximately 3 per cent.

Good results have also been secured by the Cincinnati Traction Co., where a suburban line of 25 miles in length has been bonded with twin-terminal bonds. Practically no failures have been experienced and the bond is said to be easily installed by ordinary unskilled labor. In the May, 1915, issue of Electric Traction is a description of the new Waterloo-Cedar Rapids line in Iowa; 4/0 twin-terminal bonds are employed and were installed at the rate of 100 bonds per day by four men with electric drills.

In contrast to the complimentary experience of these companies is to be found the opinions of a number of engineers who for one reason or another have not been pleased with this bond. The Bay State Street Railway Co. reports that they have used some twin-terminal bonds but found them short lived on account of breaking at the terminals or loosening of the studs.

Company 24 reports that of a trial installation in 1910 of 1000 twin-terminal bonds 75 per cent were stolen in 1913–14. With a number of these the studs, as well as the body of the bond, were removed showing that the contact was poor.

The Virginia Railway & Power Co. installed a few of these bonds but was not entirely pleased with the results obtained.

Several engineers have been consulted who object to drilling into the heads of rails, saying that it is likely to weaken them and increase the chance for cupping. This argument, however, does not appear to be founded on definite facts.

That the contact resistance of twin-terminal bonds, as ordinarily installed, increases gradually with time seems to be a well-established fact. Some of the answers to question 18 giving information on this point are here repeated. Company 7 says:

A new twin terminal bond will equal about 3 feet of rail, when the old ones will average about 4½ or 5 feet.

Company 11.—We have found no difference in resistance between old and new bonding, so long as the bonds remain unbroken and their terminal contacts are unimpaired.

This statement is made with reference to twin-terminal and compressed-terminal bonds.

Company 26.—Tests of compressed-terminal bonds and twin-terminal bonds are practically the same, 4 to 4½ new, 5 to 6 when old.

The letter from Company 20, quoted above, also states that the resistance of unsoldered twin-terminal bonds increases after installation, in some cases slightly and in some cases materially.

The Bureau of Standards recently tested 40 joints on the Washington, Baltimore & Annapolis Railroad near Washington. These joints were bonded with 4/0 twin-terminal bonds which had been in service about seven years on 80-pound rails. The test was made on 3 feet of joint, and the highest and lowest resist-

ances were 9.9 feet and 6.0 feet of adjacent rail, respectively, the average being 6.90 feet, or 0.0000828 ohm.

A test made by the Bureau of Standards on a single-rail joint, newly bonded by the American Steel & Wire Co., with one 4/0 twin-terminal bond, showed a 3-foot joint with plates bolted in place to have a resistance of 0.0000349 ohm or 2.91 feet of 80-pound rail and with plates removed to have a resistance of 0.0000745 ohm, which is equivalent to 6.2 feet of the adjacent 80-pound rail. While this latter figure is not materially less than the resistance of the average old joint it is much lower than that of individual joints. The joint plates undoubtedly add somewhat to the conductance of joints even on old installations but just how much it is difficult to say. The tests conducted by the Bureau of Standards on unbonded joints which have been referred to before indicate that on old joints the function of the plates as far as aiding the return circuit is concerned is practically nil. It is altogether possible that observed changes in the resistance of bonded joints have frequently been attributed to deterioration in contacts when as a matter of fact they have been largely the result of loosening and rusting of the joint plates.

Considering all of the information at hand it appears to be more than probable that twin-terminal bonds as well as other mechanically applied bonds gradually increase in resistance with time. This increase in resistance with the twin-terminal type, though small in some cases, becomes quite appreciable in others, and on the average remains within the limit of good practice for a period of years, on joints which have been carefully installed.

That the use of solder in connection with these bonds will forestall this contact depreciation is undoubtedly true. Its adoption, however, should depend upon local conditions and the personnel of the force of workmen.

Summing up the features of the mechanically applied head bond we find the following to be applicable to both types here discussed.

These bonds are short and therefore comparatively inexpensive. They can be rapidly installed with very little interruption to traffic, the total cost of installation, including bond, being about 50 cents each on new work. When used on city streets they can

be installed without removing joint plates, but on this type of construction they are subjected to vehicle traffic, which is likely to shear them off of the rail. On open track they are subject to theft, but this loss is much smaller than with longer bonds. It can be reduced by painting with black paint, thus rendering the bonds less conspicuous. In some cases they have been protected by iron plates bolted to the joint. Owing to the shortness of the bond, failures frequently occur from breaking of the strands, particularly on poorly maintained joints. The contact between copper and steel slowly, though as a rule not seriously, depreciates. This may be prevented by soldering and to some extent by tinning the terminals.

(*e*) Electric-Weld Bonds.—The practically universal demand for something better than a soldered contact and a substitute for the purely mechanical contact has been responsible for the wide adoption of the electric-weld bond within the past few years. The 720 000 of these bonds reported by the operating companies is an indication of the extensive use which it has found during the comparatively short period of its manufacture. Although it has been used for the most part as a head bond it is now coming into use more and more for concealed application to the web of the rail.

There seems to be practically no question regarding the permanency of the contact that these bonds make with the rail, but some criticism has been directed against some of their other features, particularly to the breaking of the ribbons and to the inconvenience of using the bonding car on tracks over which traffic must be maintained. The question has also been raised as to what effect if any the welding heat has on the steel of the rail. The following quotations from written reports and conversations, it is hoped, will throw some light on these questions.

The New York State Railways, of Syracuse, are using large numbers of electric-weld bonds where they are believed to be the best bond available. The engineers state that they can be installed in paved streets by removing a couple of bricks and the expense is not over 60 cents per bond, while the replacement of a concealed bond on similar construction would cost about $3. When installed in macadam streets a wire is twisted about the middle of the bond to prevent the ribbons from separating and

working to the surface. The need of this precaution has been recognized by the manufacturers, who now provide bonds with a clip as shown in Fig. 17. The company has been using the EA type and has experienced a rather high percentage of failures from breaking of the ribbons. Recently, however, the ET type has been adopted from which much better results are expected. These two types are shown in Figs. 4 and 5 and have been previously discussed.

The New York Railways, of Rochester, are using practically nothing but electric-weld bonds. On new work where there is heavy traffic a concealed bond is welded to the web of the rail and an EA and an EB type to the head, making three bonds per joint. Very little trouble from traffic is experienced in paved streets, but in macadam and earth streets a number of bonds have been broken by vehicles. This company has also recently substituted the ET for the EA type.

The Hudson & Manhattan Railroad Co. is using 600 000 cir. mils electric-weld bonds and finds them satisfactory for new work. They are not so satisfactory for maintenance as the bonding car can not be derailed in the tunnels, and the expense of operating it at night for small repair jobs is excessive. This company claims that if the carbon electrodes are kept well back on the bond terminal and not allowed to fuse the ribbons near the bend in the bond that good results may be obtained with the EA type.

COMPANY 14.—After a great deal of experience here and elsewhere with various types of bonds, we have come to the conclusion that an electric-weld bond of considerable length to give the bond the proper flexibility is the only type of bond to use.

The experience of Company 13, which has been quoted under answers to question 6, is similar to that of other companies in that the ET bond has been substituted for the EA type and better results are expected from it.

Unfortunately, this new type has not been in service a great while and the companies are not prepared to make definite statements regarding it. The fact, however, that no complaints have been heard concerning it is good evidence that it is an improvement upon the EA type and will show a much smaller percentage of failures.

Regarding injury to the rail by heat there seems to be very little definite information. A number of engineers have expressed a question or fear regarding this point, but with possibly one or two exceptions no company has definitely reported any broken rails from this cause. The Cleveland Railway Co. states that several rails have cracked where bonds have been copper welded to the web of the rail.

The Los Angeles Railway, which has over 300 000 electric-weld bonds, writes the following letter in reply to an inquiry on this question:

> In reply to your letter of the 3d instant regarding broken rails as a result of heating the web in applying bonds, wish to advise that in the several thousand brazed bonds we have installed under the plates or concealed on the web we have never had a broken rail caused by heating the web.

It is reported that some fractures have occurred in rails through holes which had been punched in the web, but that such failures are easily prevented by reaming out the holes, thus relieving the strain around them.

In the absence of more definite complaint on this score it is safe to say that the injury to rails resulting from the heat generated in welding rail bonds is so small as to be negligible and can be practically disregarded in the selection of a type of bond.

The matter of interruption to traffic is something that will depend upon local conditions and will have to be met by each company in a manner depending upon a variety of circumstances. A number of companies operate their bonding car at night on tracks from which it is difficult to divert the day traffic. Upon suburban tracks, for maintenance work, it is usually possible to sidetrack the bonding car, or if not it may be derailed to accommodate infrequent traffic.

The following is a summary of the properties and features of the electric-weld bond:

The bond is made for either head or concealed application. Either type can be installed on new work for from 50 cents to 60 cents. The head bond is short and has experienced a rather high percentage of failures from the breaking of the ribbons, as well as from ignorance and carelessness in its application. Modern improvements are materially reducing these failures.

The bond makes a very low-resistance contact with the rail, which does not depreciate with time.

The shortness of the bond and the strength of the contact has made the theft of this type, on interurban lines, far less than that of other types.

The bond is used successfully in paved and other types of city streets, where it can be cheaply installed. Being subjected to vehicle traffic, however, occasional failures must be expected. Where used in earth or macadam streets a clip should be employed to prevent the ribbons from working to the street surface.

The installation of this bond is accomplished with the aid of a bonding car, the first cost of which is not justified on small properties.

Maintenance bonding can not be accomplished without interruption of traffic or considerable inconvenience in derailing the car or operating it at night.

Some fear has been expressed regarding the heating of the rail webs, but the failures from this cause have been so infrequent that no great importance should be attached to them.

The following account of the apparatus and methods used in connection with the electric-weld and the copper-weld rail bonds was furnished by the Electric Railway Improvement Co. Some of the apparatus referred to is shown in Figs. 6 and 6*a*.

ELECTRIC-WELD RAIL BONDS

On direct-current lines electric-weld rail bonds are installed with a small car measuring 6 feet 10 inches in length and about 5 feet 10 inches in width. The frame of the car is of structural steel covered with an oak floor and carried on four 20-inch wheels.

The electrical apparatus consists of a rotary converter and transformer with the necessary switches, circuit breakers, controller, resistances, etc., for its safe and convenient operation.

The rotary converter is provided with a clutch and is used as a motor for the propulsion of the car along the track.

The bonding clamps for electric welding are located at both sides at one end of the car over the rails and have adjusting screws with hand wheels for bringing the same into position for service.

To avoid interference with traffic, a screw jack with bevel-gears termination in cranks at each side of the car, is fixed under the center of the car frame. By means of this jack the car can be raised for the purpose of turning and rolling from the track to avoid interference with traffic. Depending on conditions, the car can be removed from the track in from one to one and a half minutes and may be replaced on the track in a similar length of time.

The entire car is covered with a canopy top which carries the trolley pole.

On alternating-current lines the car is not necessary, and the AC voltage is carried directly from the trolley to a portable transformer. The welding clamp is attached to the transformer, which is provided with wheels for rolling along the track. This apparatus may be lifted from the track in a few seconds.

On high-tension lines the trolley voltage would pass through a step-down transformer before entering the portable.

For electric welding, a current of from 25 to 50 amperes is drawn from the trolley; this varies, depending on the trolley voltage and the size of bond to be attached. For welding a 4/0 rail bond to the rail, an alternating current of about 2500 amperes at 5 volts is employed, which is obtained on a direct-current line by converting and transforming about 25 amperes at 550 volts taken from the trolley. To make a weld, the current is applied for a period of from 45 seconds to 2 minutes, depending on conditions.

An average of 100 4/0 bonds per 10 hours may be installed with the car operated by a bonder and two helpers. For best results the bonder should be a man of average intelligence, while the two helpers may be laborers.

The welding apparatus is not sold by the manufacturer, but is put out under a lease. The clauses of most importance in the lease are those stipulating that during the life of the patents all rail bonds installed with the apparatus shall be purchased from the manufacturer at prices given in schedules attached to the lease, that the prices for bonds as given in the schedules are guaranteed by the manufacturer and the only change in the prices is due to the fluctuation of the market price of lake ingot copper in the bonds, that the manufacturer will furnish an expert to instruct the railway company's men in the proper operation of the apparatus, and at the expiration of the patents, under which the apparatus is leased, the manufacturer will transfer title in the apparatus to the lessee.

COPPER-WELD RAIL BONDS

The bonding cars as put out by the manufacturer carry a melting furnace suspended from the rear of the car for copper welding. This type of welding is especially adapted to the installation of large conductors around special work, and for attaching feeder cables, etc., to the rails. Bonds and cables of any capacity may be attached by this method. It is also used for joining third rails both electrically and mechanically together.

Copper welding is effected by pouring molten copper. A mold of suitable refractory material is employed, the size of the same depending on the section of the conductor and the size of the terminal or contact area desired. The end of the conductor lies in the terminal mold. A short channel connects the terminal mold proper with another chamber or reservoir. The rail having been properly cleaned at the point of weld, the mold with the bond wires is clamped in position. The molten copper, on being poured into the mold, impinges on the ends of the bond wires and the steel at the point of weld, and flows on into the reservoir, which finally becomes filled; continuing to pour the molten copper, it backs up into and fills the terminal mold. The excess of copper poured over that required to form the bond terminal proper has the effect of raising the temperature of the steel within the area of the bond terminal, to a proper welding heat; the steel then readily unites with the molten copper present.

The mold is then removed and the block of copper formed by the reservoir is taken off by cutting with a chisel the small section of copper which connects it with the bond terminal.

Copper welding may be used to electrically and mechanically join third rails.

The copper-welding outfit is also furnished independent of the bonding car. This particular apparatus is operated with kerosene oil, the crucible containing the copper being placed in a furnace similar to the one used in the coke outfits.

The copper-weld furnace car is equipped with from three to five kerosene furnaces and is designed for use on large installations.

The copper-welding apparatus is put out under a lease similar to that used in the case of the electric-weld cars.

This method of bonding, while being adapted for installing large cables, etc., is especially suited for bonding steam-road electrifications and new electric lines where the electric power is not available at the time of installation. For this type of work it is not necessary to have any of the apparatus on the tracks while operating. In fact, the single kerosene-furnace outfit may be carried along by two men, and need never occupy the track.

A modification of the Electric Railway Improvement Co.'s bonding car has been devised by the Cleveland Railway Co., and employed by them with considerable success, particularly for their special work bonding. In this process, which is described in the Electric Railway Journal of August 7, 1915, silver solder is used for a brazing metal instead of brass, and the union of the bond with the steel is therefore affected at a much lower temperature than is necessary with the standard equipment. It is claimed that the lower temperature and a different arrangement of electrodes enable the bond to be applied with a much smaller current than is used by the regular bonding car. This smaller current is obtained by a small rotary converter which can be mounted on a motor truck and connected to a step-down transformer by flexible conductors. The transformer is carried about from joint to joint over an entire intersection and with no interruption to traffic. It is claimed in Cleveland that this modified equipment and method has made possible the bonding of special work on a daylight schedule and with no broken rails or interruption of traffic.

(*f*) Oxy-Acetylene-Welded Bonds.—This type of bonding is accomplished by welding bonds with forged or cast terminals to the rail, usually the head, and employing pure or fluxed copper to build up the terminal of the bond along the rail head. So far, it has not found a very wide application, although it has been used in Minneapolis and St. Paul for a number of years with

FIG. 18.—*Apparatus for applying bonds with the oxy-acetylene flame*

FIG. 19.—*Apparatus for applying joint plates with the electric arc*

marked success. It possesses practically all of the advantages of the electric-weld bond and is free from the objection of requiring an expensive equipment and of interfering with traffic. Although it does not make quite as strong a contact with the rail as does the electric-weld bond, the contact is permanent and does not deteriorate with time. No injuries to rails have been reported from the use of the flame which apparently does not produce a higher temperature in the rail than is generated by the electric weld.

The Minneapolis Street Railway Co. has the following to say with respect to their practice of bonding:

The only type of bonds used during the past three or four years is a 250 000 cir. mils, U shaped, T head, bond welded on the side of the head of the rail, and in special cases on the side of the flange of the rail or on the base of the rail, using acetylene torch for welding. We use this type of bond on all types of construction from the light rail in earth streets to 100-pound guard rail on special work in paved streets, and on heavy T rail construction laid on concrete base with block, asphalt, or stone paving. We have at present between 14000 and 15000 such welded bonds in service.

Unskilled labor is used for bonding work; that is, the laborers are instructed in the proper handling of the tools and are then competent to do the work. It is found unnecessary to do any cleaning of the steel before welding bonds. For acetylene welding we use compressed acetylene in acetone tanks and compressed oxygen in tanks, with torch specially developed for this class of work. Pure copper is used for welding and no flux is required.

Complete cost of installing welded bonds of 250 000 cir. mils capacity in large numbers is between 50 and 60 cents per bond including cost of tools and machinery.

The failure of this method of bonding to have found more extensive use is apparently not the result of any defects or disadvantages connected with the process, but is more than likely the result of other causes. The recent concerted action of the manufacturers of both bonds and acetylene in providing and advertising proper bonds and material for this method of bonding will no doubt act as a great stimulus to its further adoption.

The following statements regarding this method of bonding rail joints have been abstracted from information submitted by the Ohio Brass Co. The apparatus referred to is shown in Fig. 18.

OXY-ACETYLENE-WELDED BONDS

For applying rail bonds the equipment consists of the necessary tanks of compressed oxygen and dissolved acetylene, which may be purchased by the railway companies direct from the manufacturers, who have warehouses and factories quite generally distributed over the country, thus insuring prompt and convenient service.

A pressure regulator and set of gauges are provided for both the oxygen and acetylene tanks. These are changed from tank to tank as they become empty, the empty tanks being returned to the manufacturers of the gas. A hose extends from each set of pressure regulators and is connected to a blowpipe or torch by means of which the gases are mixed and adjusted to give the proper condition of the flame.

A grinder for cleaning the rails will also be required and may be either of the electrical or hand operated type. A pair of colored goggles to protect the eyes of the operator will be found advisable for constant work, although the rays of light from the oxy-acetylene flame do not affect the eyes and skin as do the rays from the electric arc.

A small truck provided with handles will be found convenient for conveying the tanks of gas in service and can be purchased from the manufacturers or built from blue prints furnished by them.

Clamps for holding the bond to the rail while welding on one terminal will be supplied by the manufacturers, as will also the necessary flux wire. The latter is a metal especially prepared for the purpose of attaching the bond to the rail and for building up the head of the bond. It is three-sixteenths of an inch in diameter and is furnished in coils of about 50 pounds, which the customer should cut into suitable lengths.

For the proper application of bonds the work of only three or four men is required; a working foreman who watches and assists the blowpipe operator; blowpipe operator; and one or two grinders, the number depending on whether an electric or hand grinder is used. The grinders have time for other necessary duties as well.

The bonds require on an average about 3 cubic feet, at atmospheric pressure, each of oxygen and acetylene, and the actual time required to apply a bond is from four to five minutes.

(*g*) Bonding of Manganese and Other Special Work.—The recent use of manganese steel for special work which is too hard to drill has led to some difficulties in bonding. On this point Company 3, in speaking of electric-weld bonds, says:

This method of bonding manganese special work and steam-railroad crossings has been the only one that we have had any success with so far, on account of not being able to drill the manganese steel for compressed type. Some of the steel companies have undertaken to insert a soft-steel plug in the rail which can be reamed out to receive the bond terminal, but we find that the contact between the plug and steel is insufficient to carry current for any time.

Other companies report no such trouble from inserts in manganese steel, and the failures in this particular instance may have been due to the fact that the plugs were inserted in the rails by the aid of an oxyacetylene flame rather than having been cast in as is customary.

Company 27.—We bond around all important special work where any quantity of current is to be provided for by welding (with an oxyacetylene flame) heavy copper lugs to the web or base of the rail joint. To these lugs are attached stranded weatherproof covered cables of from 500 000 to 2 000 000 cir. mils, cross section, which spans the entire special work.

Question E–W–84 in the May issue of the A. E. R. A. asks what is the best method of bonding manganese special work and railroad crossings other than by using the plug holes provided. The following answers to this question as found in the June and July numbers are given below:

CHAS. E. FRITTS, ELECTRICAL ENGINEER, METROPOLITAN STREET RAILWAY CO., KANSAS CITY, MO.—We use copper cables underneath the special work and single bonds by brazing.

EDW. J. BLAIR, ELECTRICAL ENGINEER, METROPOLITAN WEST SIDE ELEVATED RAILWAY CO., CHICAGO, ILL.—The best way of bonding manganese special work and railroad crossings is to jump around them with copper-cable conductors, making the connection to ordinary rails behind the manganese special work.

A. V. BROWN, ENGINEER MAINTENANCE OF WAY, LAKE SHORE ELECTRIC RAILWAY CO., SANDUSKY, OHIO.—Run cable around manganese special work.

H. P. BELL, ELECTRICAL ENGINEER, SAN FRANCISCO-OAKLAND TERMINAL RAILWAYS CO., OAKLAND, CAL.—In bonding special work and railroad crossings, we have found, after much investigating, testing, and experience, that it is cheaper and more efficient to bond around crossings and special work (unless electrically continuous and easily drilled) with such size cables as the current density and voltage drop allowed demand at that particular location. We place such cable or cables in trunking filled with tar compound and bury them about 6 inches below the tie, connecting them to the through rails by means of seven-eighths-inch separate compression-bond terminals. Thus the track special work may be repaired or replaced without necessary repairs to bonding.

C. L. CADLE, ELECTRICAL ENGINEER, NEW YORK STATE RAILWAYS, SYRACUSE, N. Y.—The New York State railways' practice has been for the last seven years to install welded bonds on all track joints needing electrical connections. From our experience the welded bond adheres to manganese rail and special work as well as open-hearth and Bessemer steel. At railroad crossings in addition to bonding the joints each crossing is jumpered by placing a piece of 4/0 copper cable, or larger, around the crossing, so that in case the bonds on the joints of the special work are broken off the current will be carried through the jumper cable.

C. D. EMMONS, GENERAL MANAGER, CHICAGO, SOUTH BEND & NORTHERN INDIANA RAILWAY CO., SOUTH BEND, IND.—We use brazed bonds for all of our work.

H. G. THROOP, SUPERINTENDENT LINE AND BUILDINGS, NEW YORK STATE RAILWAYS, SYRACUSE, N. Y.—I believe that the best method of bonding manganese special work is to use welded bonds to the head of the rail, double bonding, using a 10-inch and 18-inch bond. The special work should also be cabled, i. e., one 500 000 c. m. cable installed for each track, attaching the ends of this cable to two 4/0 cross bonds welded to the rail at a point back of the special work each way from the crossing.

H. F. MERKER, ENGINEER MAINTENANCE OF WAY, EAST ST. LOUIS & SUBURBAN RAILWAY CO., EAST ST. LOUIS, ILL.—On account of the fact that special work with heavy cables carrying current around it may be considered dead for all the time except when a car is passing over it, there have been various methods of bonding used. In fact, some engineers have gone so far as to leave all bonds off of such special work. We know of no better way to bond special work than to leave a soft plug for drilling a

bond hole, but this hole may be placed at any convenient part of the special work piece and need not be in line with the bolt holes or near them, as all that is really necessary is one tap connecting it with the return circuit to keep the switch piece alive, and it is not necessary that each joint be bonded.

E. H. Schofield, Engineer Power and Equipment, Minneapolis Street Railway Co., Minneapolis, Minn.—In addition to cables spanning special work and bonded to rails, bonds may be welded by acetylene torch to the side of the head or guard of special work parts.

H. A. Clarke, General Manager, Ithaca Traction Corporation, Ithaca, N. Y.—My experience has been that it is the best practice to bond around such special work, using bond terminals of whatever type may be in use, soldered to sufficient length of 0000 copper wire.

J. B. Tinnon, Engineer Maintenance of Way, Chicago & Joliet Electric Railway Co., Joliet, Ill.—I know of no better method of bonding manganese steel special work than by using the plugs in the castings. It is almost impossible to weld any kind of bond to the manganese casting and the heating of the casting would no doubt tend to destroy the value of the manganese steel. It is also nearly impossible to drill the casting, so I think that the method of using the plug holes and bonding to a through cable is the best method that has yet been developed.

H. E. Gough, Engineer, Elmira Water, Light & Railroad Co., Elmira, N.Y.—We double bond all connections in special work, drilling the bond holes on the ground. Better connections are insured if drilling is done on the ground rather than in the shop. It is also generally wise to provide supplementary bonding around special work where the traffic is heavy.

Geo. H. Pegram, Chief Engineer, Interborough Rapid Transit Co., New York, N. Y.—We find it most convenient and satisfactory to have all bonded holes provided by the manufacturers with copper plugs for signal bonding. We do not use manganese rail for negative return, as we have an opportunity to make use of the open-hearth steel guard rail for that purpose. The guard rail is bonded to manganese rail by means of clipped bonds.

In a paper presented at the annual convention of the Southwestern Electric and Gas Association, Galveston, Tex., May, 1915, G. W. Smith, engineer, San Antonio Traction Co., San Antonio, Tex., said:

Our experience with rail bonds as ordinarily applied has not been such that we felt justified in depending on them to carry the current around the special work. We tried to get information as to whether or not copper cables could be welded to the steel rail by the thermite process, but in so far as we were able to find out this had never been done, so we proceeded to do some experimenting. The result was that we succeeded in making a weld which gives a contact area equal to or greater than the cross-section area of the rail. The cable used, which is 800 000 cir. mils, is welded to the lower side of the flange of the rail, and a section cut through the weld shows a shading in color from steel at the top to copper color at the bottom of the weld. The cable enters the weld at the bottom and is therefore in contact directly with the copper film at the bottom of the weld, which insures minimum contact resistance. We are using this method of bonding on all reconstruction work.

The opinions here expressed are overwhelmingly in favor of bonding around special work. In several answers no mention is made of bonding the individual members of the special work. Although they are called upon to carry current only when a car is passing over them, it is obviously good practice to provide for at least light bonding to the main return circuit.

Although the consensus of opinion seems to be in favor of welding or brazing bonds to manganese steel, a number of engineers are apparently having good results from the bonds installed in the soft plugs provided by the steel companies. Only one answer refers to the possibility of injuring the manganese steel by welding bonds to it. Experience, however, seems to be sufficiently complete to show that any fear regarding such injury is unwarranted.

(*h*) Bonding of Converted Steam Roads.—The bonding of steam railroads in preparation for electrification presents some problems somewhat different from those obtaining on the ordinary city or suburban track. The conditions which are, as a rule, similar, are briefly as follows: (1) Joint plates are in place and the removal of them would not only be expensive but unsafe with the passing of high-speed trains; (2) the location is usually such as to invite theft of exposed bonds; (3) safety is of prime importance, and the adoption of any bonding method from which a broken rail might possibly result could not be permitted.

These conditions have forced several railroads to the adoption of a special type of bond which, so far, has been confined to this class of work. The objection to the removal of joint plates excludes the concealed type of bonds and necessitates the use of either a short bond or one long enough to span the plates. Objection has been made to the short head bonds both on account of the breakage of the strands and ribbons under heavy traffic as well as to the alleged injury done the rail by the welding heat and the drilling of the head. As the adoption of a long exposed bond would mean continual loss and trouble from theft, a long compressed or pin terminal bond has been devised and adopted by several railroads which can be inserted under the joint plate and locked in position by the removal of a single bolt. This bond

is provided with one terminal attached and one detached, and a sharp crimp or loop is put in the body of the bond near the end containing the fixed terminal. One of the end bolts of the joint plate is removed and the bond is threaded under the plate from this end. When the bond is in its proper position the bolt is replaced, which engages with the loop and locks the bond. The loose terminal is then soldered to the end of the bond and expansion or compression of the terminals is then affected in the ordinary manner. It is stated that in the electrification of the Chicago, Milwaukee & St. Paul Railroad this type of bond will be used and that it was adopted only after an exhaustive study of the subject. The Pennsylvania Railroad and the New York, New Haven & Hartford Railroad are also using this or similar types.

(*i*) DOUBLE V. SINGLE BONDING.—The proper size and number of rail bonds per joint appears to be a subject regarding which very little definite knowledge exists, and the present practices of the operating companies seem to be based upon arbitrary and irrational rules rather than upon theoretical considerations.[1] W. A. Del Mar, in a letter published in the Electrical World of April 1, 1909, comments upon the absence of information and standard practice upon this point, and gives the following four rules as having been used by the operating companies to determine the capacity of bonds:

(1) Making the conductor equal in capacity to the rail.
(2) Asking advice of manufacturers.
(3) Doing what other people have done.
(4) Guessing.

Realizing the irrational character of these rules, Mr. Del Mar attempted to determine the proper capacity of bonds by the following three more logical considerations:

(1) Determine the magnitude of the continuous and maximum currents in the rail and make the bond large enough to prevent undue heating.

(2) Make the bond large enough to give at least 90 per cent efficiency to the return circuit; that is, make the conductance of the bonded rails at least 90 per cent of the conductance of a

[1] The Bureau of Standards is now making preparations to conduct experiments on the carrying capacity of different types of bonds under various conditions. The results of these experiments will be published at a later date.

theoretically continuous rail. The following equation is given by Mr. Del Mar for the efficiency of the return circuit:

$$\text{Eff.} = \frac{L_1}{L_1 + \frac{L_2(1-K)}{K}}$$

where K = average efficiency of bond, or the ratio of the conductance of the bond to the conductance of an equal length of rail.

L_1 = length of rail,

L_2 = length of bond between terminals.

(3) Make the bond large enough to conform to proper mechanical conditions.

The author of the letter states that he was immediately frustrated in his attempts by having no data on the capacity of bonds, and after a thorough search through trade literature and scientific abstracts he came to the conclusion that no work was available as to the amount of current that short bonds would carry under various conditions without undue heating. He suggests this as a splendid field for research by the colleges and commercial laboratories and scores the manufacturers for not having data on the capacity of their various bond products.

That this subject is of immediate and practical interest, and one on which a great diversity of opinion exists, is shown by the following answers submitted to question E–W–88, asking for the practice of the companies regarding single and double bonding, published in the June and July issues of the A. E. R. A.:

C. D. Emmons, General Manager, Chicago, South Bend & Northern Indiana Railway Co., South Bend, Ind.—We single bond our track in all cases excepting in city streets where leading to power stations.

H. F. Merker, Engineer Maintenance of Way, East St. Louis & Suburban Railway Co., East St. Louis, Ill.—Where the return current is large and where a bad electrical joint would be serious, or where paving conditions make the opening of joints a serious matter, there is no doubt that double bonding is to be preferred. Remember the old maxim, "Do not carry your eggs all in one basket."

John Leisenring, Signal Engineer, Illinois Traction System, Springfield, Ill.—This company has adopted the practice of double bonding all track in pavement or other forms of streets. The tracks on private right of way are only single bonded.

H. P. Bell, Electrical Engineer, San Francisco-Oakland Terminal Railways, Oakland, Cal.—We practice both double and single bonding of rails, depending upon the current density, allowable voltage drop, size (conductivity) of rail, and capacity of bond.

Charles E. Fritts, Electrical Engineer, Metropolitan Street Railway Co., Kansas City, Mo.—Double bonding.

A. H. Babcock, Consulting Engineer, Southern Pacific Co., San Francisco, Cal.—Tracks are both single bonded and double bonded, according as the load requirements change with varying localities. No hard and fast rule can be laid down, but bonding should be done always with reference to the potential gradient in the rail.

A. V. Brown, Engineer Maintenance of Way, Lake Shore Electric Railway Co., Sandusky, Ohio.—Double bond all tracks in pavements.

Edward J. Blair, Electrical Engineer, Metropolitan West Side Elevated Railway Co., Chicago, Ill.—it is our practice to single bond our tracks, but this is rather a matter for local conditions to determine. Whenever the resistance of the return circuit can be kept within bounds by single bonding, it should be done.

C. L. Cadle, Electrical Engineer, New York State Railways, Syracuse, N. Y.—The practice of this company has been to bond each joint with at least one 4/0 bond. At locations where the current density is such that the size of this bond will not carry the current imposed on it, as high as five bonds are installed at each joint to take care of the additional current.

H. A. Clarke, General Manager, Ithaca Traction Corporation, Ithaca, N. Y.—I would state it is the practice of this company to single bond our tracks.

George L. Wilson, Engineer of Maintenance of Way, Minneapolis, Minn.—The Twin City Lines use only single bonds. It has never been the practice of this company to double bond its tracks.

H. G. Throop, Superintendent Line and Buildings, New York State Railways, Syracuse, N. Y.—It is a good practice to double bond tracks which are heavy carriers of return current to the power house from congested districts and also to double bond in congested districts. In both Utica and Syracuse this practice is followed throughout the central portions of the city and on lines to which the greatest amount of negative cables, which lead back to the power houses, are attached. This method also gives some insurance for good bonding, as of course the two bonds give greater life than a single bond.

George H. Pegram, Chief Engineer, Interborough Rapid Transit Co., New York, N. Y.—We double bond our rail joints.

H. E. Gough, Engineer, Elmira Water, Light & Railroad Co., Elmira, N. Y.—We double bond our tracks in the central portions of the city and where traffic is heavy. In outlying sections single bonding is used. We are using a pin-terminal bond for this purpose.

J. B. Tinnon, Engineer Maintenance of Way, Chicago & Joliet Electric Railway Co., Joliet, Ill.—We single bond tracks except where the return flow is very high, and then we double bond. The practice of double bonding for the purpose of having one good bond in case the other fails is, I think, a waste of money, as the same condition that causes one bond to fail will also cause the other to fail in most cases.

J. C. Donald, General Superintendent Asheville Power & Light Co., Asheville, N. C.—Bonding both track rails with cross bonds located every 200 feet is considered good practice.

F. M. Richards, Electrical Engineer, Atlantic Shore Railways, Kennebunk, Me.—It has been our practice to single bond our tracks, installing cross bonds between rails every thousand feet.

These answers throw absolutely no light on the question as to just what is the safe carrying capacity of rail bonds. That a short copper bond attached to heavy masses of cold steel can not attain a dangerously high temperature is obvious even when carrying currents of the magnitude found on heavily loaded tracks. The contact resistance of one terminal of a mechanically applied bond in good condition is in the order of 0.000005 ohm. When carrying a current of 500 amperes, which is greatly in excess of currents ordinarily found in rails, there would be a dissipation of only 1¼ watts, and with 1000 amperes a dissipation of 5 watts per terminal. This is, of course, in addition to the heat generated in the copper of the bond, but as far as the contact is concerned there seems to be no practical limit to its capacity to carry current.

Parshall in England, in an article on "Earth returns for electric tramways," published in the Journal of the Institution of Electrical Engineers, April 28, 1898, stated that experience with pressure contacts in central station work had demonstrated that 100 amperes per square inch was the safe limit, but suggests that 50 and even 25 amperes per square inch would be found more advisable for rail bonds. As these figures are exceeded in practically all installations in this country they can not be regarded in any way as a practical limit for current density.

A reference to the above answers will show that a number of companies, including some in large cities, install only single bonds and that several employ double bonding only when necessary to reduce the potential gradient on the tracks. This would indicate that double bonding is not necessary solely from the standpoint of capacity, but that its adoption is demanded by other considerations. One of the usual causes for its use is to insure safety, and not place reliance on a single bond in a permanent track where the repair of a bond would mean tearing up the pavement.

Under extreme conditions double bonding is justifiable solely from the economic standpoint, and the factors which determine these conditions may also be used to determine the economic

replacement of deteriorating bonds. These conditions can be determined when the constants of a given system are known and the cost of power and the average current in the rails are obtainable.

Let W = weight of rail per yard,

I = root-mean-square current in rail over a 24-hour period,

p = cost of power per kilowatt hour in dollars,

P = cost of installing a bond,

n = number of years bond will last,

L = reduction in joint resistance resulting from installation of bond, expressed in feet of adjacent rail,

r = rate of interest paid on invested capital;

then the resistance of the rail is very close to $0.001/W$ ohm per foot and the annual saving of energy in dollars due to installing a bond would be $I^2 \times \frac{0.001L}{W} \times \frac{p}{1000} \times 24 \times 365 = \frac{0.00876 I^2 Lp}{W}$

The annuity [2] required to retire the investment, P, on a new bond at the end of n years, its period of usefulness, is

$$P\left(\frac{R-1}{R^n-1}\right) \text{ where } R = 1 + \frac{r}{100}$$

When the annual power loss without the bond exceeds this annuity, it is obvious that the installation of a new bond would be a matter of economy. The limiting condition would be obtained when the energy charge is equal to the annuity. Equating these two we get: $0.00876 \frac{I^2 Lp}{W} = P\left(\frac{R-1}{R^n-1}\right)$, from which any quantity may be obtained provided the others are known. If we employ the equation to determine at what current double bonding becomes economical, we have

$$I^2 = \frac{WP}{0.00876\, Lp} \times \frac{(R-1)}{R^n-1}$$

In order to apply this equation with six independent variable factors it will be necessary to assume a set of values which would obtain under normal conditions.

[2] American Handbook for Electrical Engineers, p. 830.

Let it be required to determine whether one or two 4/0, 10-inch compressed-terminal bonds should be used on 100-pound rails being newly installed under the following conditions:

p = cost of energy = \$0.01 per kw. hr.
P = cost of installing bond = .60
n = life of bond = 12 years.
r = rate of interest = 5 per cent

The resistance of one 10-inch 4/0 bond, including contact resistance, is very close to 0.000055 ohm, and would probably average more. Two such bonds in parallel would have approximately one-half of this, or 0.0000275 ohm, which is also the decrease in the resistance of the joint resulting from the installation of the second bond. As a 100-pound rail has a resistance very close to 0.00001 ohm per foot, L would be 2.75 feet.

Substituting these values in the above equation we find that I^2 is equal to 15 660 or $I = 125$ amperes.

The Bureau of Standards has examined numerous railway load curves and has found that the ratio of the root-mean-square current to the all-day average, ranges from 1.25 to 1.4. If we use the lower of these values, which is more applicable for the heavily loaded lines with which we are concerned in this discussion, we get 100 amperes as the all-day average value of the current. With a load factor of 40 per cent this would give 250 amperes per rail as the value at the peak period.

While the values here assumed are normal in every respect, they are undoubtedly on the side tending to make the limiting current small. A lower cost of energy, a shorter life of the bond, and a higher cost of installing a bond will all tend to give a larger current where double bonding becomes economical. As the values assumed for these three variables are obviously near the limit in the other direction, it is difficult to conceive how the economy point would be reached at any all-day average current value much less than 100 amperes.

While a current of 100 amperes all-day average is entirely possible and undoubtedly exists on the rails of many properties, it is far in excess of what good electrolysis conditions would dictate. One hundred amperes on a 100-pound rail would give a drop of 1

volt per 1000 feet, and as 0.3 to 0.4 of a volt per 1000 feet, average for the 24-hour period, is considered the limiting potential gradient, consistent with good electrolysis conditions, it is seen that the latter condition would limit the current in the rails long before economy would demand double bonding.

It is true that double bonding will reduce the potential gradient in rails, and several of the engineers quoted above seem to consider this as a determining factor for this practice. Its influence in this respect is quite small, however, as will be seen from the following calculations:

Consider 10-inch 4/0 concealed bonds on 100-pound rails as before. With 60-foot rails we have approximately 59 feet of rail in series with the bond and the resistance of the two are 0.00059 and 0.000055 ohm, respectively, or a total of 0.000645 ohm. Adding a second bond would reduce the resistance by 0.0000275 or to 0.0006175 ohm, which is 95.73 per cent of the resistance of the rail with one bond. With 30-foot rails the effect would be more marked, and the maximum effect on the potential gradient resulting from the addition as a second bond would be where a short-head bond is installed on a joint previously bonded with a long-cable bond around the joint plates.

A 30-foot rail bonded with a 36-inch 4/0 compressed terminal bond will have a resistance made up as follows: 27 feet of rail, 0.00027 ohm, 3 feet of 4/0 copper, 0.00015 ohm, two contacts, 0.000013 ohm, or a total of 0.000433 ohm, of which 0.000163 ohm is due to the bond. If now a 4/0 electric-weld bond having a resistance, including contacts, of 0.000045 ohm be applied to the head of the rail the long bond will be shunted by approximately 2½ feet of rail in series with the short bond or by 0.00007 ohm. The two bonds in parallel will have a resistance of 0.0000487 ohm, making the resistance of one rail length of circuit 0.0003187 ohm, which is 73.6 per cent of the resistance before the application of the second bond. With 80-pound rails, 60 feet in length the corresponding figure would be 87.3 per cent.

These calculations will substantiate the statement that, except perhaps under extreme conditions, double bonding in lieu of single bonding has only a secondary effect upon the potential gradient in return circuits and therefore upon electrolysis condi-

tions. When the potential gradient therefore begins to approach the maximum allowable limit, or the limit set by good practice, other and more effective means should be employed to reduce it.

In all of the above calculations the effect of the joint plates has been neglected. Their effect would be to increase the conductance of the joint and therefore reduce the necessity of double bonding.

Considering only tracks in which the potential gradient does not greatly exceed the values considered safe from the standpoint of electrolysis we find that neither carrying capacity, economy, nor voltage drop will justify the practice of double bonding under ordinary conditions. The only factor remaining, therefore, which might justify the use of two or more bonds is that of insurance against the total failure of a bonded joint.

It is difficult to say to what extent the probability of a joint failure is reduced by the addition of a second bond. If the failures are the result of loose joints the second bond is not much of an insurance, while if failures are the result of imperfect workmanship in installation the value of the insurance is much greater. It is altogether possible that two bonds of different types could be used to advantage for this purpose rather than bonds of the same type. A long bond around the joint plates might act as an insurance against the failure of a concealed bond and a concealed bond might insure the joint against theft of the exposed type. In employing a second bond as an insurance against the total failure of a joint it, of course, acts to improve operating and electrolysis conditions as well, to say nothing of reducing the power loss in the return circuit. These advantages when considered together will ordinarily justify the use of the second bond on new and permanent tracks which are being installed in paved streets, where inspection of bonds is difficult and repairs expensive. The additional expense of installing the second bond at the time the new track is being laid is relatively very small and, in general, will be returned in reduced maintenance costs. The practice of double bonding would, perhaps, not ordinarily be justified on open track where the inspection and repair of bonds is less expensive and where the traffic as a rule is lighter.

(*j*) Economic and Other Considerations for the Replacement of Bonds.—The installation of a bond on a joint already bonded may be considered either as a replacement or as double bonding, and no sharp line of distinction between the two conceptions can be said to exist. The term "double bonding" has been used with reference to joints on which two bonds are originally installed or where a second bond is installed to supplement a new or old bond in a practically perfect condition. The term "replacement" will be used with reference to bonds installed to supersede or supplement old bonds which have failed or which are in a state of deterioration.

The value of the resistance which a deteriorating bond must reach before economy will justify its replacement can be determined from the equation given on page 98 of this paper, in which the reduction in the joint resistance resulting from the installation of the new bond becomes the unknown quantity.

Transforming the equation for this purpose we find that

$$L = \frac{WP}{0.00876\, I^2 p} \times \left(\frac{R-1}{Rn-1} \right)$$

The following concrete example will illustrate the application of this formula. Let us assume:

W, the weight of rail per yard = 100 pounds.
P, the cost of replacing a bond = $0.80.
p, the cost of energy = 0.0050 per kw. hr.
n, the life of the new bond = 10 years.
r, the rate of interest = 5 per cent.

Let us also assume that the current is of such a value as to give a drop of 0.8 volt per 1,000 feet as an all-day average on a perfectly bonded rail. This is greatly in excess of the current permitted by good electrolysis conditions and is not ordinarily exceeded, even in regions where the problem of electrolysis does not exist. The resistance of a 100-pound rail is 0.01 ohm per 1,000 feet, which would limit the average current to 80 amperes. Taking 1.3 as the ratio between the root mean square and the all-day average current we get for our equation $I = 104$ amperes.

The replacement cost of a bond is usually greater than the cost on new work and is therefore taken at 80 cents. One-half cent

per kilowatt-hour for power may seem low, but as it is assumed to be the cost of energy which will be saved by the application of the bond, it would not be logical to load it with fixed charges and operating costs other than the fuel. Upon this basis it is high rather than low.

A replacement bond is often installed on old track which is partially worn out and which may be entirely replaced within a few years. Ten years, therefore, is considered as a liberal life for the new bond. The srcap value of bonds is small and is neglected in this discussion.

Substituting these values in the above equation we find that $L = 13.4$ feet. As the new bond itself will test equal to from 3 to 6 feet of rail this means that the old bond will test equal to about 18 feet of rail before a new one can be installed with economy. This is, of course, far beyond the point of deterioration which good practice has established for the replacement of bonds. Electrolysis and voltage conditions ordinarily, therefore, demand a better return circuit than economy itself can dictate. In fact, it is doubtful if economy alone in many circumstances will justify any but the cheapest and simplest type of bonding. The Bureau of Standards [3] and numerous independent investigators have demonstrated beyond a doubt that the character of most electric roadbeds is such as to shunt a large fraction of the current from the rails even when well bonded. With poor bonding the increased gradient along the track tends further to increase the leakage current which might easily reach a large per cent of the total current, except in the immediate vicinity of the negative bus. Parshall, in an article previously referred to, makes the following statement:

> In tests recently carried out in a line some 8 miles long it was found, by cutting the track at the middle of the line and inserting an ampere meter, that some 60 per cent of the current was returning through the earth itself. Tests made as to the conductivity of the earth return showed as a whole that it was about one and a half that of the rails, bonds, and fishplates, which would indicate that on an average about 33 per cent of the current was leaving the rails. In other words, the voltage drop in the earth return was but two-thirds of what it would have been had the current been wholly in the rails.

[3] The Bureau of Standards is now engaged in investigating the resistance of different types of roadbeds under various weather conditions. Tests are being conducted on experimental tracks built for this purpose as well as upon city and suburban lines. A full account of this work will be published at a later date.

In this connection the experience of the Virginia Railway & Power Co. is of interest. They report that several years ago the bonds on an alternating-current line of several miles in length were failing rapidly as the result of incorrect methods and poor workmanship on the original installation. A complete rebonding of the tracks meant a heavy expense which the road at that time was not prepared to meet. A careful study of the situation was made and after ascertaining that bonds were being omitted on a number of modern European alternating-current lines it was decided to continue operation without rebonding and to keep a careful record of the energy consumption from year to year. After three years of this practice, during which time practically all of the original bonds had failed, the road is in successful operation and no increase in energy consumption chargeable to poor bonds has been noted.

Such a condition as here described would, of course, be utterly impracticable on an ordinary direct-current system on account of the pernicious electrolysis conditions which would obtain, to say nothing of poor operating conditions.

The one thing which calls for and demands good bonding is good electrolysis conditions. Without the incentive to guard against trouble from this source it is difficult to say to what degree of deterioration a company is justified in allowing its return circuit to descend.

(*k*) STANDARDS FOR REPLACEMENT.—The practices of the companies regarding the replacement of bonds, as recorded in Table 1 on page 32, indicate a wide variety of standards, ranging from 3½ feet of rail to 27 feet of rail as the limiting resistance of joints. Among the answers there was not a single suggestion as to the manner in which any particular standard was established.

The selection of a standard for replacement should be governed almost wholly by local conditions. There are so many elements to be reckoned with that it is practically impossible to suggest a hard and fast rule that would be applicable under all circumstances. Even if such a rule or formula could be developed it would contain so many variable factors and qualifying considerations as to make its application impracticable.

Frequent objection has been made to the universally adopted practice of referring to the resistance of a bond in terms of a

length of adjacent rail. The practice is a convenient one but obviously irrational, as it gives no indication of the actual resistance of the bond unless modified by supplementary data. The length of the joint tested, the length of the bond, and the weight of the rail must be known before the resistance of the bond in ohms can be calculated. A logical standard of replacement should obviously include these several factors, which would, however, greatly complicate the simple rule now in general use. It has been suggested that the replacement resistance of a bond should be defined in terms of its increase in resistance over that of a similar bond newly and properly installed rather than in some arbitrary length of adjacent rail, but this also has its objections. The increase in the resistance of a bonded joint results from breaking of strands and ribbons, corrosion of terminals, and loosening and rusting of plates, thereby reducing their ability to aid the bond. With welded bonds the deterioration from corrosion of the contact is nil while with the long cable bonds its effect on the total resistance of the bond is far less than in short concealed or head bonds. A standard therefore based upon, say, a 100 per cent increase in resistance, would be as irrational and arbitrary as one based upon a given length of adjacent rail. Moreover, with most of the standard bond-testing instruments, giving the resistance of a joint in terms of adjacent rail it would be difficult to discontinue the practice of referring to bonds in these terms.

A standard which is simple, definite, and workable, even though it does not always meet the demands based upon a rigid technical analysis of the subject, is much to be preferred to one which attempts to meet these demands but is clumsy, complicated, and impracticable. A standard of replacement based upon the resistance of a given length of adjacent rail possesses the advantages here enumerated and from the standpoint of practical considerations is not so irrational as may at first appear. After all, the factors which limit the resistance of bonded joints are, ordinarily, electrolysis and operating conditions, and both of these are determined by the potential gradient in the return circuit. If, therefore, we assume the same current density in rails of different weights, which is by no means a violent assumption, we are consistent in basing our standard on a given length of rail, inde-

pendent of its weight, thereby limiting the voltage drop across the joint rather than its resistance in ohms.

As to what this standard should be is a matter that should be determined largely by local conditions. Different standards might well be employed by a single company to meet the conditions on different types of construction or in regions requiring different degrees of electrolysis protection. It is altogether probable that it would be found advisable in some cases to employ different standards on city and suburban tracks. Answers to question 5 would indicate that the limiting resistance for a 3-foot joint of from 6 to 10 feet of adjacent rail would ordinarily fall within the bounds of good practice. Greater lengths might be employed in regions where no trouble from electrolysis is likely to exist, but on city streets these values should not be exceeded.

3. WELDED AND SPECIAL JOINTS

It has been previously stated that the information available relative to the life and character of different types of welded joints is far less complete than that upon the subject of rail bonds. Some of the reasons for this lack of reliable information are set forth in the following quotation from one of the prominent electric railway engineers of the country:

In my experience I will say that I consider the information gotten from the furnished answers from questions as above to be unreliable. There are but very few cities in which the engineering department has been in existence or that the engineer has held his position long enough to be able to make any statement about worn-out rails or worn-out joints. The intensity of traffic and the weight of cars bears an important relation to the life of rails and joints and the conditions vary in different cities, and have varied so from conditions of 10 years ago that very few men are capable of intelligently answering the questions.

Also the change in the material of which rails are made has been so great that unless this is considered the information is unreliable. The first Bessemer rails of a girder type were rolled about 1884. These rails were structurally defective, and the rail mill did not know how to roll the girder rail. Girder rails at this period weighed 56 pounds to the yard and were about 4½ inches high. By 1890 the girder rail had grown in height to 6 inches and some of the sections were such that they could be properly rolled, but many engineers were still using sections that could not get the proper treatment in rolling. About 1893 the 9-inch girder rail was coming into general use and girder rails commenced to be a success. The rails rolled from 1890 to about 1901 were Bessemer made from a good grade ore and gave a long life. About 1904 the grade of ore formerly used for making Bessemer rails was getting extremely scarce, so a lower grade was used, and for the next two or three years the rails furnished street railroad

companies were not as good as formerly furnished, and at this time the weight of cars had been materially increased, so that track life was short. About 1909 the open-hearth rail came into general use and apparently gives a very much better rail than that furnished previously, although the open-hearth rail has not been in use long enough to give absolute results on its life and durability.

The increase in carbon in the steel used in rails has materially affected the reliability of the welded joint in some locality.

Realizing as we do that the conditions here described are true to a large degree, we do not feel justified in attempting a close analysis of facts or in drawing any but the most cursory and general conclusions from the data and information at hand. The several types of welded and special joints will be taken up in turn and a brief summary of the facts available will be presented. Conclusions will be drawn and recommendations made only where the facts seem to warrant such.

(*a*) THE CAST WELD.—The compilation of figures under question 1 on page 49 show that of the 268 052 electrically continouus joints reported, 149 716, or more than 50 per cent of the total, are cast welds. In consideration of the fact that the installation of this joint has been practically discontinued these figures are an indication of an early popularity at a time when the welding of rail joints was looked upon by many as a rather bold experiment.

The excellent results and long life obtained from this joint as reported by a number of companies, under questions 4 and 6, would seem to indicate that the discontinuance of its use in recent years is not the result of its inability to meet the conditions imposed upon it, but rather to the fact that other and more modern types of joints are meeting the requirements of service and installation in a more satisfactory manner.

Several causes are given as responsible for the failures of the cast weld. A frequent cause of complaint is that a true weld is not effected and the rails loosen up in the joint. This not only augments wear and cupping but adds materially to the resistance of the joint. Some operators are inclined to the view that the cupping of the rails at the joint is frequently due to the softening of the steel, which is said to result from the excessive heat of the molten metal. This is apparently the most serious fault that has been found with the cast weld and is no doubt largely responsible for the almost total abandonment of this type of weld which has

occurred in recent years. The large amount of molten metal used in the cast weld maintained the rail ends at a high temperature for a considerable length of time, and the slow rate of cooling had an annealing and softening influence which was later manifest in cupped and worn rail heads.

None of the modern welding processes employ the large amount of metal that was used in the old cast weld, and the cooling is consequently much more rapid. Moreover, the greatest heat is now confined to the web and base of the rail, and it is therefore extremely doubtful if the heads of modern steel rails are seriously injured by any of the welding processes in use at the present time. The cupping which so frequently develops in cast-weld joints may also have been augmented by a difference in the resilience between the joint and the adjacent rail or to imperfect surfacing, either of which would give rise to pounding and uneven wear on the rail.

In 1908 Parshall, in an article already referred to, has the following to say regarding the cast weld:

> Another method of somewhat the same nature as the process of welding is that known as the "cast weld," or the "Falk joint." This joint is made by pouring molten metal into a metal mold clamped round the rail joint. The surfaces of the cast metal that come in contact with the mold and with the rail joint are chilled, and are thus prevented from forming a perfect weld. I believe it has been asserted that a weld is effected. It seems, however, extremely doubtful, since without the use of a flux a weld is almost impossible between cold wrought steel and molten iron. The rail expands after the metal is poured around it, and remains expanded until after the cast iron has set, and finally resumes its former size. This affords a slight clearance for expansion and contraction, and accounts for the mechanical success of the joint, which, if carefully applied, makes when new a perfect mechanical track; although, in the writer's mind, the difference of resilience between the part surrounding the casting and the remaining part of the track may eventually cause uneven wearing away of the rail.
>
> The clearance above spoken of undoubtedly admits a certain amount of moisture, so that by the formation of oxide the resistance of the joint increases in the course of time. From the results of tests which I have at hand, it also appears that the electrical resistance of this joint, even when new, varies considerably; so that, considering the low voltage restrictions in this country, it should be used in connection with an efficient form of bond. Owing to the rigidity of the joint, however, copper bonds will undoubtedly be found more durable in conjunction with it than with a fishplate form of joint.

(*b*) THE THERMITE WELDED JOINT.—The failures of the thermite weld and the rather large percentage of cupped joints which have been reported from time to time have been for the most part on

the old type of weld and should not be considered as evidence against the greatly modified and newer joint which is referred to on page 20. Very little evidence is at hand regarding this modified type of weld, but if it is successful in preventing the cupping of the joint one of the chief objections to the thermite weld will have been removed. In contrast to the old cast weld the thermite weld requires but a small amount of welding metal, and this metal actually unites with the steel of the rail to obliterate the joint. The small amount of metal and the perfect union contribute to give the joint a resilience practically the same as that of the adjacent rail, and the wheel is thereby enabled to pass without encountering a hard spot in the track. Moreover, the metal being continuous, the joint has a high conductance which does not deteriorate.

Among the objections to the thermite weld has been recorded the facts that the process is comparatively slow and that in repair work where it is necessary to insert a short length of rail to take the place of a badly cupped railhead two distinct welds are necessary where other processes require only a modification of a single weld. These conditions are said to make the process less satisfactory on old rail than for new work.

The San Antonio Traction Co. adopted the new thermite weld in the reconstruction of their tracks, which was begun in October, 1913. A full account of the work was given by G. W. Smith, engineer for the company, in a paper presented at the annual convention of the Southwestern Electrical and Gas Association, at Galveston, Tex., in May, 1915. Mr. Smith made the following remarks:

> We have made a total of 3000 welded joints on track laid with concrete roadbed, and since the tracks have been put in operation we have had two breaks in the rails. One of these occurred at a crossover in the fall of 1914 and the other near a bridge in the winter of 1914. The first welds were made in the winter of 1913, and these have been through two winters and one summer. The joint which broke near the crossover is in this lot. The joints which were put in in the summer of 1914 have been through one summer and one winter, and the joint near the bridge was in this lot. In so far as we are able to judge from our experience of the past 18 months, we are convinced that, from the mechanical as well as electrical standpoint, the best type of permanent construction is obtained by welding the joints in the rails and using steel ties in concrete.

As the new type of thermite joint has been in operation for only about two years, it is too early to form definite opinions regarding it. That it is an improvement over the earlier types, however, there seems to be no question. Reports from other companies who have adopted it or who have installed it on an experimental basis will be looked forward to with interest.

(*c*) THE ELECTRICALLY-WELDED JOINT.—The relatively small number of 11 697 electrically-welded joints which were reported in answer to question 1 is no indication of the extent to which this type of joint is being used at the present time. Its use is confined for the most part to large properties where the Lorain Steel Co. is installing it by contract in great numbers. It is being used largely for reclaiming old track where cupped joints are repaired by using a "dutchman" and extra-long splice bars. Four welds are required on such joints instead of three, and the expense and time is about one-third greater than for an ordinary joint. The popularity of this type of joint is due largely to the rapidity with which it can be installed and the consequent small amount of interference with traffic. The conductivity of the joint is 100 per cent or better, which is greatly to its advantage.

The Boston Elevated Railway Co. has several hundred miles of new and old track welded by this process, for which Harry M. Steward, chief engineer of maintenance of way, has only words of praise. He declares this to be the cheapest method he has found for reclaiming old track which is cupped and in bad condition. He says, further, that breaks are more prevalent in old than in new rails, and attributes this to the fact that old rails have strains in them which are sometimes responsible for the fractures which are developed with the welding heat. These fractures usually occur through one of the holes of the rails, and it is said that if new rails with no drillings are welded that no breaks would occur. In fact, Mr. Steward says that the failures on their new rails have been practically nil.

The Worcester Consolidated Street Railway Co. installed 7800 electrically-welded joints in 1902, which have given entire satisfaction. Few failures have occurred, and the most of these have been fractures through bolt holes.

Company 10 has used the electrically-welded joint on old rails with cupped joints which they wish to maintain for six or seven years. They do not advocate the joint on new work, as they believe the spot welding introduces strains into the web of the rail which are likely to cause subsequent failures.

A head-supporting splice bar has been developed and is used on the rail sections which have shown a tendency to fail from a depression of the head. This splice is shown in Fig. 10.

Summing up the evidence at hand we find that the electric-weld joint has been used in the past principally for the reclaiming of old and partly worn rail, and there only where comparatively large contracts have made the use of the elaborate equipment practicable. The joints have a conductance equal to or greater than the solid rail and are welded rapidly. Badly cupped joints are welded by using a "dutchman," extra-long splice bars, and four instead of three welds. The local and intense heating of the web introduces strains into the rail which frequently are the cause of fractures and breaks. Such failures are less frequent on new than on old rails, and particularly less frequent on undrilled rails.

The following information regarding this welding process has been prepared from statements submitted by the Lorain Steel Co.:

ELECTRICALLY-WELDED RAIL JOINTS.

The electrical welding of rail joints by the Lorain Steel Co.'s process is done exclusively by them under contracts entered into with railway companies. The Lorain Steel Co. furnishes all apparatus, material, and labor for welding the joints. The railway company supplies the necessary current for operating the welding equipment and prepares the track ready for welding. Where repair work on old rail is to be done, this consists of removing the paving around the joints to the bottom of the rail, the ties not being disturbed; removing the old splice bars and bond wires, and bringing the rail ends to the proper surface and line. New rail is welded either before or after the paving is done, a space being temporarily left around the joint in the latter case. After the welding is completed the railway company replaces the paving. Where traffic is not heavy the work can be carried on continuously, day and night. On double track portable crossovers are made use of by the railway company for diverting the traffic. In sections where the traffic density is too great to permit of the use of crossovers the work is done between the hours of midnight and 4 or 5 a. m. The portability of the welding equipment making it easy to weld in one place for a few hours and then move to some other locality. About 15 minutes are required to complete a joint. Three welds are made on the standard and head-support joints, and the current is on about 2 minutes for each weld. At 500 volts about 250 amperes are required,

or about 125 kw., this current being on for 6 minutes to each joint the power consumption amounts to about 12½ kw. hrs. per joint. The parts to be welded are brought to a welding heat by means of the resistance offered by the materials to be welded to a large flow of current under a low voltage. The current is used simply for heating and no arc is formed. The welding current is supplied at about 7 volts. After the proper degree of heat is attained the current is cut off and the parts are forced together under very heavy pressure which is held in place until the metal has cooled below the critical temperature of crystallization or recalescence.

The process is applicable to all kinds of track construction where the motive power to be used is electricity. In welding open track on elevated railways or on surface lines on private right of way, expansion joints are made use of to provide for expansion and contraction. These are placed from 800 to 1000 feet apart and at the ends of all curves.

A welding equipment consists of four cars, provided with railway motors, and is operated in three units. The first car contains a motor-driven air compressor and a sand-blast apparatus. With this the rails and bars, at the points where the welds are to be made, are entirely cleaned of dirt and rust. For the second operation of welding two cars coupled together are provided. The first of these cars carries the welding transformer and pressure apparatus suspended from a crane, in the car to the rear of this a rotary converter, inverted, changes the direct current from the trolley to an alternating current. A regulator maintains the welding voltage practically constant at 300 volts regardless of the fluctuations of the trolley voltage. A range of from 325 volts to 650 volts direct current can be operated on. The current from the regulator is passed to the welding transformer, and is here stepped down to the welding voltage, of about 7 volts with about 25 000 amperes. The bars are placed over the joint, one on each side of the rail web, and the welding contacts are brought into place to engage the middle of the bars, and this weld is made first, after which one end of the bars is treated and then the other end. In this way the bars are in an elongated state when the ends are welded and on cooling off exert a powerful pull to bring the rails ends together, thus leaving practically no joint at all. In the car carrying the rotary converter a switchboard carries instruments for recording the voltage and amperage. In the welder car suitable water tanks and circulating system is provided for circulating water through the welder transformer and the contacts to keep them cool. The third operation consists of grinding the head of the rail to a true running surface, and the last car carries suitable grinding machines for this purpose. This car also carries a furnace for melting the spelter used in making the head-support joint. The cars have been so designed that they can be readily loaded on gondola freight cars and are shipped from city to city in this manner.

Where it is necessary to ship the equipment by railroad the company requires 3000 or more joints to make it justify them in taking a contract, but where the machines can be run over trolley tracks they accept work for as few as 500 joints.

(*d*) THE ARC-WELDED JOINT.—The application of the electric arc to the welding of rail joints is comparatively recent, and although numerous companies have installed a few arc-welded joints as an experiment, many of these have not been in service long enough to afford reliable information as to their ability to meet the demands of service. Moreover, the arc has been used

in the construction of so many different types of joints that time alone will be able to determine their relative merits.

Special plates as shown in Figs. 11 and 12 are manufactured by the Indianapolis Switch & Frog Co. and have undergone several changes and improvements during recent months. Formerly the ends of these plates were brought to points instead of being cut off as shown, and this brought two welding seams to a juncture at the base of the web. With a similar plate applied on the opposite side of the rail two more seams were brought to the same region. This condition resulted in numerous breaks through the base of the rail and led the company to adopt the modified form of plate here shown. Not only have the plates been cut off to prevent the juncture of the welding seams but one plate is made slightly higher than the other, and they are then staggered longitudinally. The result is that no two seams come directly opposite each other and the rail at no point is heated by more than one seam. It is claimed by the manufacturers that these modifications have greatly reduced the possibility of failures from fractures.

The following information regarding this welding process has been prepared from statements submitted by the Indianapolis Switch & Frog Co.:

ARC-WELDED PLATES.

A general view of the welding outfit as manufactured by the Indianapolis Switch & Frog Co. is shown in Fig. 19. This welder, which consists largely of resistance coils to reduce the potential at the arc to about 70 volts, is mounted on light wheels similar to those of a wagon, weighs 1700 pounds and costs $500 f. o. b. cars at Springfield, Ohio. One man can place this outfit alongside the track and perform the welding without interruption to traffic, but a helper is usually provided to remove the trolley pole for passing cars and to assist generally in the work. The operator himself should be a man of intelligence, initiative, and ingenuity, and is usually paid from $2.50 to $4 per day. The current strength required is from 150 to 180 amperes and the time necessary to weld a joint is variously reported at from 30 minutes to over 1

hour. The energy consumption, therefore, based on 175 amperes and a time of 45 minutes is 72.2 kw. hrs. per joint on a 550-volt circuit.

The Simplex joint plates, shown in Fig. 11, cost from $1.95 to $2.25 and the Apex type of plates, shown in Fig. 12, from $3 to $3.50. The welding steel, which is supplied in various grades by the company to meet different requirements, is relatively a small item.

Where it is necessary to maintain traffic over joints which are being welded, the plates are held in place by two bolts temporarily installed instead of by the clamps shown in Fig. 19. In order to reduce the liability of overheating the rail in any one place the following instructions have been issued by the company to all purchasers of plates:

In case of old rails, remove rust, grease, pitch or moisture, using an old file or wire brush, and, if necessary, the carbon arc.

Spot each end of each plate, first on the base line, then on the top line, for a distance of about 1 inch, to insure holding the plate in position and to resist the tendency to kink or creep during welding.

Run a heavy fillet of steel around edges of plates, drawing a pocket or cavity in both the edge of the plate and the rail. This is important. At the same time deposit a globule of the molten electrode, filling in the cavity and building up at least one-fourth inch.

Weld plates as follows (refer to Figs. 11 and 12): (*a*) Weld on base line from each end to center; (*b*) weld opposite plate the same; (*c*) return to the first plate and weld from the base upward on the sloping cut on each end of the plate; (*d*) weld both ends of opposite plate in similar way; (*e*) return to first plate and weld along top of plate, beginning at the end and welding to the center; (*f*) weld top of opposite plate in same manner; (*g*) do not attempt to weld across the undercut at ends of plates, as the point is cut off to prevent joining the two lines of welding.

Some companies are welding standard fish plates or angle bars to the base and head of the rail, while still others are using bolted or riveted joints and welding only the base, such modifications being designed principally to overcome the objection to heating the web of the rail.

That the use of the arc-welded plates is justified from the mechanical standpoint alone is shown by the fact that they are being used successfully in Cincinnati, where the double-trolley system makes rail bonding unnecessary. F. J. Venning, superintendent of construction for the Cincinnati Traction Co., states

that standard plates are used for this purpose and that they are welded along the head of the rail and to a plate or shoe placed under the base of the rail. The joint costs about $4 and is said by Mr. Venning to be cheaper and better than the continuous joint. Incidentally, Mr Venning states that the company is making most of its frogs and special work, using old rails and the arc welder for the purpose, and is saving as much as 50 per cent on some jobs.

The Dayton, Springfield & Xenia Southern Railway Co. is using the electric arc to weld their rail joints to Abbott base plates. They also spot weld the nuts on the joints, which prevents them from working loose.

The Springfield Railway Co., of Springfield, Ohio, is introducing arc-welded joints on all straight work. Steel ties are used, and these are spot welded at all rail ends, thus affording good cross bonding. George C. Towle, general manager of the company, predicts that all city tracks will be welded within a few years, possibly including special work as well. He states that the manganese steel now being used will last from 10 to 15 years, and can therefore be welded the same as straight work, but that its high resistance will probably necessitate supplementary bonding.

The Ohio Electric Railway Co. installed a number of arc-welded joints in Springfield, Ohio, more than a year ago, and during the first winter a number of rails broke outside of the welds. A number of these breaks occurred on rails where the pavement had been completed on only one side and are therefore attributed to excessive contraction during the cold weather. It is also said that the rails have a particularly high carbon content, which might account for the high percentage of failures.

The Columbus Railway, Power & Light Co., of Columbus, Ohio, is using a special joint, which is illustrated in Fig. 20. Special plates, which hug the web of the rail with practically no clearance, are carefully bolted to the rails after reaming the holes for a driving fit. These plates are welded to the base of the rail, and a short section of a Carnegie steel tie is inverted under the joint and also welded to the base of the rail. E. O. Ackerman, engineer of way for the company, claims that this joint is not only eco-

nomically installed, but that it is giving excellent results, with no failures. He does not like the idea of heating either the head or web of the rail and believes that a head support is essential to best results. These features he has incorporated in the special joint here described.

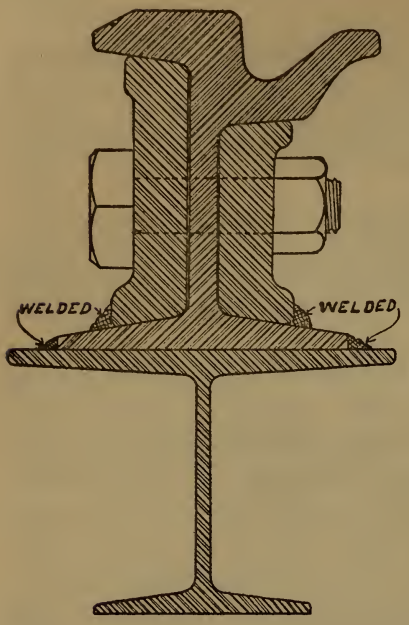

FIG. 20.—*Combination welded and bolted joint used in Columbus, Ohio*

The Butte Electric Railway Co. is using the electric arc to repair all broken thermit welds and also to some extent on regular construction. They are not afraid to heat the head of the rail as is shown in Fig. 21. In explanation of this figure the company says:

This drawing shows our method of welding this particular joint. With other types of rails and joints the manner is varied to suit the type. For instance, in welding a joint on a 52-pound T rail, angle and bolt joint, we use a welding plate which will be just wide enough to reach from the flange of the angle bar to the top of the rail, and we weld the plate to the top of the rail and to the angle bar. We use the carbon for melting or cutting down the rail ends at the joint, afterwards filling it up with steel. Of course, on this type of joint the angle bar can not be welded to the bottom of the rail.

This drawing does not show the longitudinal extent of the weld in the head of the rail at the joint, which is about 2 inches.

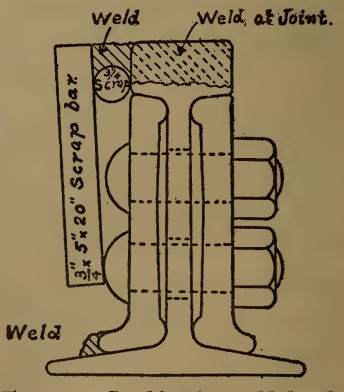

FIG. 21.—*Combination welded and bolted joint used in Butte, Mont.*

One of the principal objections which has been found to the arc-welded joint is that the process is slow, requiring about one hour per joint. However, as the welding can be done without interruption to traffic and requires the time of only two men this objection is not serious. The energy

consumed is considerable, but even when figured in at a liberal rate the total cost of a joint is lower than for most other types of welds.

(*e*) THE CLARK JOINT.—This joint, as used in Cleveland, and a modification of it as used in Baltimore, have been briefly described on page —. They resemble the special joint used in Columbus, Ohio, and shown in Fig. 20 in that they are a combination of a high-grade bolted joint and a welded joint, the thermit shoe shown in Fig. 22 taking the place of the weld on the Columbus joint.

This joint has been standard with the Cleveland Railway Co. since 1906, where 50,000 of them are in operation, and where only three failures have been recorded. The joint is said to cost from $4.60 to $5.

The modified Clark joint is standard with the United Railways & Electric Co., of Baltimore, where they report no failures up to the present time. The joint is said to cost from $7 to $9.

The Clark joint, or one similar to it, has also been installed in Buffalo. H. L. Mack, superintendent of tracks and lines of the International Railway Co., states that in installing these joints he bonded one rail leaving the other without bonds. Subsequent tests showed the unbonded joints to have an efficiency of from 60 to 70 per cent while the bonded joints showed about 90 per cent.

While the electrical efficiency of this type of joint is undoubtedly less than that of other fully welded types, it is of a permanent nature and no other form of bonding should be necessary.

(*f*) THE NICHOLS COMPOSITE JOINT.—This joint, which is described on page 22, has had rather a limited application, but has nevertheless met with excellent results in Philadelphia and St. Louis. Following is an extract from a letter from George B. Taylor, engineer of way for the Philadelphia Rapid Transit Co.:

> The Nichols composite rail joint was first used in this city in 1901, and since that time practically all of our 9-inch track has been equipped with such joints, and some of our T rail has also been so equipped; the total mileage at the present time being about 330 miles. All of the track constructed or reconstructed during 1914 had these joints applied, and we expect to apply the same during the coming season. We have removed practically none because of defects, but a small amount of track, constructed about 1902, and equipped with the Nichols joint, was removed a few years ago for the simple reason that the rail was worn out.

Over 8000 of these joints are in service in St. Louis where they report that no failures have occurred in the three years since their installation.

The joint is expensive and must be installed by experts who realize the necessity of careful work. Tests made in Philadelphia by the Bureau of Standards some years ago show that the conductivity of the joint is practically the same as that of the unbroken rail.

V. EXPERIMENTAL TESTS

During the course of its investigation of the subject of rail bonds and rail joints the Bureau asked a number of the manufacturers to submit samples of their products for experimental as well as for exhibition purposes. They very willingly responded and a number of bonded and welded rail joints were collected in this manner. These were all tested for conductance and a few specimens were tested by the department of metallurgy of the Bureau for the effect of heat on the steel.

The Bureau of Standards realizes that laboratory tests on individual specimens afford no definite indication of the value of the average bond or joint under service conditions and therefore wishes to caution against placing too much reliance upon the results here given. However, the specimens, as a rule, are normal and should give a fair idea of what should be expected of new bonds and joints of similar types. All resistances were determined by comparing them with a Leeds & Northrup 0.0001 ohm shunt, the comparison being made with a high-resistance Weston millivoltmeter. A current of about 200 amperes was used in all tests.

A description of the several bonded and welded joints tested and the results obtained are given in Tables 7 and 8. It is of interest to note that all of the bonded joints showed a much greater conductance with the plates bolted in place than when removed. Mention has already been made of the fact that tests on old unbonded joints show that a large per cent of them have a resistance greater than 1000 feet of rail and that this change in the conducting power of joint plates might easily have been mistaken in many instances for a deterioration of the bond itself.

TABLE 6

Resistance Tests on Bonded Rail Joints

[All resistances given in microhms, double contact resistance taken as the difference between resistance of joint across extremities of abutting rails and resistance of bond between terminals.]

	American Steel & Wire Co.'s bonds			Electric-weld bonds, Electric Railway Improvement Co.		Oxy-acetylene welded bonds	
	Compressed terminal	Pin terminal	Twin terminal	Head bond	Concealed bond	Prest-O-Lite head bond	Ohio Brass Co. head bond
Weight of rail (pounds)	80	80	80	65	65	90	80
Length of joint plates (inches)	34	34	34	24	24	26	.....
Number of bolts in joint plates	6	6	6	4	4	4	(a)
Capacity of bond	4/0	4/0	4/0	4/0	4/0	4/0	4/0
Circuit length of bond (inches)	10	10	8	4½	10	8	7
Distance on rail, center to center of terminals (inches)	10	10	3	3½	10	3½	3½
Resistance of 3 feet of joint, plates in place	(b)	43.8	34.9	62.2	66.7	37.1	.....
Resistance of 3 feet of joint, plates removed	92.7	80.1	74.5	84.5	79.9	75.5	68.9
Resistance across extremities of rail ends, plates removed	66.0	55.0	36.0	30.0	47.9	36.9	33
Resistance of bond, center to center of terminals	50.5	42.3	32.5	26.8	42.9	31.5	27.6
Double-contact resistance	15.5	12.7	3.5	3.1	5.0	5.4	5.4
Single-contact resistance	7.7	6.3	1.7	1.5	2.5	2.7	2.7
Resistance of 3 feet of joint in feet of adjacent rail, plates on	.....	3.65	2.91	3.29	3.56	3.37	.....
Resistance of 3 feet of joint in feet of adjacent rail, plates removed	7.73	6.67	6.21	5.83	5.48	6.83	5.85

[a] No plates. [b] Not taken.

TABLE 7

Resistance Tests on Welded Rail Joints

	Electrically welded joints, Lorain Steel Co.			Goldschmidt Thermite Co.'s thermite joint	Indianapolis Switch & Frog Co., arc-welded joint
	(1)	(2)	(3)		
Weight of rail (pounds)	109	122	100	104	70
Type of rail	Girder	Girder	T	Girder	T
Resistance of 3 feet of rail (in microhms)	27.5	24.6	30.0	27.0	37.56
Resistance of 3 feet of joint (in microhms)	20.4	20.4	21.6	27.3	27.18
Efficiency of 3 feet of joint (per cent)	135	120	138	99	138

At the request of one of the manufacturers the Bureau has attempted to determine what effect the heat, accompanying the welding of bonds or steel plates, has on the grain structure of the rail and to what depth a change in grain structure takes place. Several specimens were accordingly turned over to the metallurgists of the Bureau, who tested the hardness of the steel at numerous points by the Brinell test and also made microscopic examinations of the grain structure in and out of the "weld zone."

The Brinell test, which consists in measuring the penetration of a cylindrical steel point under a given pressure, showed no appreciable difference in the hardness of the steel in the "weld zone" and at other locations. However, as tests could not be made closer than about three-sixteenths inch from the edge of the steel by this method, it gave no indication of the hardness immediately adjacent to the weld.

Photomicrographs, together with the report of Dr. Merica, who made the examinations, are shown in the accompanying figures.

Fig. 23, with a magnification of about two diameters, shows a portion of the cross section of a rail after being etched, to which steel plates had been welded by the electric arc. Figs. 24, 25, and 26 show the grain structure close to the weld, at the edge of the weld zone, and in the center of the web, respectively. They are magnified to about 100 diameters.

Fig. 27 shows a portion of the head of a rail to which a bond had been applied by the oxy-acetylene flame and Figs. 28, 29, and 30 show the grain structure close to the weld, at the edge of the "weld zone," and outside of the weld zone, respectively. Fig. 31 shows a portion of the web of a rail to which a bond had been electrically welded, and Figs. 32, 33, and 34 show the grain structure close to the weld, at the edge of the "weld zone," and in the center of the web. Following is the report of Dr. Merica:

MICROSCOPIC EXAMINATION

Transverse sections of parts of the rail adjacent to the weld were polished and etched with alcoholic HCl.

That the structure had been changed by welding could be immediately seen by the fact that immediately adjacent to the weld the steel etched much more heavily. This is shown in photographs Nos. 322, 321, and 323 of specimens 855, 858, and 857, respectively (corresponding to Figs. 23, 27, and 31).

Upon microscopic examination of the structure within and near this "weld zone" it was seen that this zone represented that metal which had suffered grain growth or

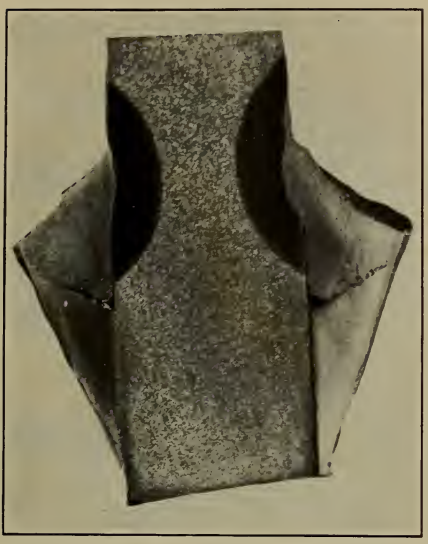

FIG. 23.—*Heat penetration in arc welding*

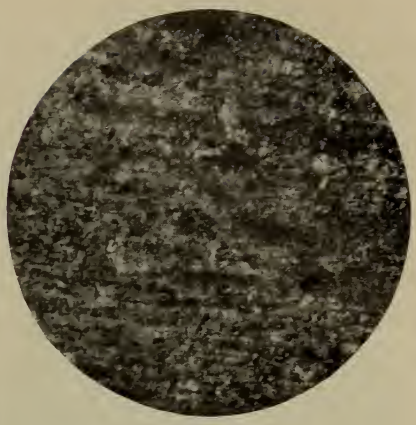

FIG. 25

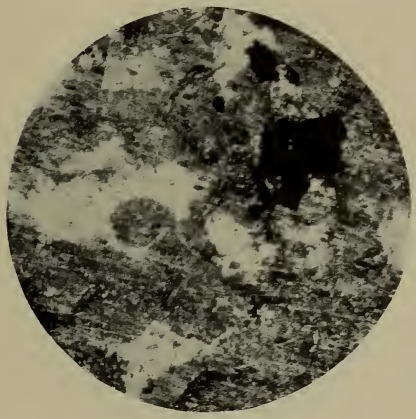

FIG. 24

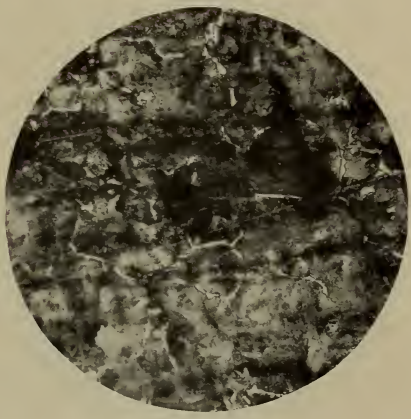

FIG. 26

FIGS. 24, 25, and 26.—*Photomicrographs showing grain-structure of steel after arc welding*

FIG. 27.—*Heat penetration in oxy-acetylene welding*

FIG. 29

FIG. 28

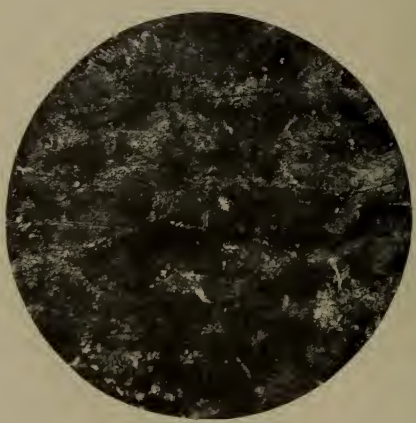

FIG. 30

FIGS. 28, 29, and 30.—*Photomicrographs showing grain-structure of steel after oxy-acetylene welding*

FIG. 31.—*Heat penetration in electric welding*

FIG. 33

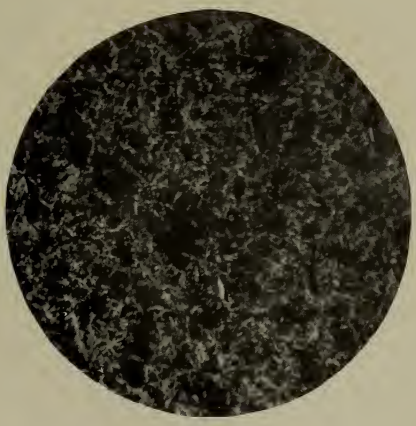

FIG. 32

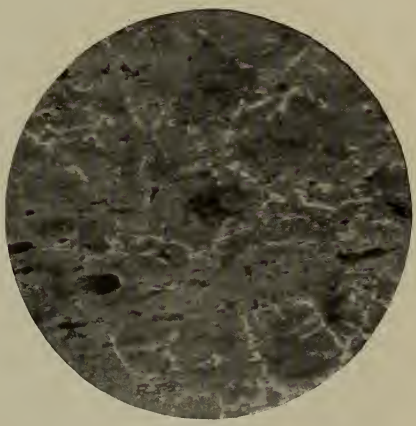

FIG. 34

FIGS. 32, 33, and 34.—*Photomicrographs showing grain-structure of steel after electric welding*

recrystallization. At the extreme edge of the copper (or steel) the metal had been heated above 700°, the transformation point, and had recrystallized, cooling rapidly to form a fine-grained structure. Near the edge of the zone the metal had been heated just under the transformation point and had merely undergone grain growth, as evidenced by the coarser structure at this point. Without this zone no change in structure had taken place. The zones vary in depth up to 0.8 cm.

This change in structure can not be considered serious from the standpoint of the wear of the rail.

VI. GENERAL CONCLUSIONS

Owing to the great number and variety of details involved in the foregoing discussions a complete summary of all data and conclusions will not be attempted. Attention, however, will again be called to some of the more important features of the subject under consideration.

Among the most important tendencies as revealed in the investigation is the attitude which the companies are now taking toward the whole subject of bonding. That it is an engineering problem deserving of as much skill and attention as any other problem in connection with the operation of an electric railway is apparently being realized by the large majority of the railway engineers. The testimony given herewith shows a marked tendency to get away from all types of soldered bonds which, even in recent years, have been installed in great numbers. A few companies who employ thoroughly experienced and careful workmen still continue to use them but the number is relatively small.

Practically all types of standard modern bonds, when selected to meet local conditions and installed according to the best modern practices, will give satisfactory results with an almost negligible percentage of failures on joints which are properly maintained. The problem of rail bond maintenance is largely that of joint maintenance. No bond can be expected to last continuously on a loose and poorly supported rail joint. No one type of bond can be said to be better than all other types. Each has its advantages and disadvantages and the selection of a bond for any particular service should be governed by the type of construction on which it is to be used, the grade of labor available for installation, and upon numerous other local conditions.

While welded joints are being used more than ever before there is also a growing tendency to adopt improved mechanical joints

and various forms of special joints, several of which are a combination of welded and bolted or welded and riveted joints. These special joints seem to be meeting the demands of service with less failures and better results generally than any of the standard types.

It has been demonstrated that the saving of power alone will not justify the best modern practice in bonding. Such practice, however, is justified and strongly recommended from the standpoint of good voltage conditions in the return circuit, which not only make for good electrolysis conditions but also for more satisfactory operation.

Attention is again called to the fact that the problem of track bonding is still in a state of evolution. New inventions and improvements in methods and practices have been so frequent during recent years that many types of bonds and joints can still be said to be in the experimental stage. Carefully kept records and a free interchange of experiences on the part of the operating companies will do much toward the establishment of definite and standard practice in this particular field.

In conclusion we wish to thank the many operating and manufacturing companies which have contributed the data and information contained in this paper. They include not only those whose names are formally recorded herein but many others, which, through personal interviews and correspondence, have rendered no less valuable assistance.

To Dr. E. B. Rosa and Mr. Burton McCollum, chief physicist and electrical engineer, respectively, of the Bureau of Standards, is due recognition for conceiving and outlining the scope of this paper, as well as for offering many invaluable suggestions regarding the collection and arrangement of the material which it contains.

Special thanks are due to C. S. Kimball, of the Washington Railway & Electric Co., who is also chairman of the committee on way matters of the American Electric Railway Association, and to Prof. Albert S. Richey, of the Worcester Polytechnic Institute, for reading this paper in manuscript and offering valuable suggestions for its final revision.

WASHINGTON, October 14, 1915.

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